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ELECTROMYOGRAPHIC FATIGUE CURVES

by

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A THESIS

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Electromyographic Fatigue Curves" submitted by Anthony Bauer in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The purpose of this investigation was to record EMG patterns during isometric and isotonic muscle contractions to fatigue. The EMG patterns were presented and discussed in the form of fatigue curves which indicated the variation in integrated EMG levels over the period of the contraction. The resulting data was recorded and analyzed using a one way analysis of variance and Newman-Keuls comparison between ordered means. The statistical data indicated significant differences in EMG levels for the different load percentages of isometric and isotonic contraction. The resulting data was also used for the construction of fatigue curves.

Ten volunteer human subjects, fifty per cent of which were female, exercised in eight different tests. Each test was run on a different day over a period of four weeks and the tests were taken in random order. Three of the tests included isometric contraction tests at thirty per cent, forty per cent and fifty per cent of maximum voluntary contraction. Four tests included isotonic contractions exercising at ten per cent, fifteen per cent, twenty per cent and twenty-five per cent of the subjects body weight. The first test involved taking basic statistics and a maximum voluntary contraction test for isometric contractions.

The results indicated an increase in integrated EMG for all muscular contraction tests. The increases were proportional to the percentage loading and, the time for the contraction was also proportional to the loading. The fatigue curves indicated noticeable fluctuations in EMG levels at specific loads whereas there was no

fluctuation at other load levels. The variation in fatigue curves was discussed in terms of muscle fibre recruitment patterns and summation of neural stimulation. Sub maximal training levels were discussed on the basis of the fatigue curves presented and on the basis of regularity of electrical stimulation. It was shown that muscular fatigue was not related to a lack of neural stimulation but to physiological failure at the cellular level.

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CHAPTER I

STATEMENT OF THE PROBLEM

A. INTRODUCTION

Electromyography is the study of muscular function by recording the electrical impulses inherent within the muscle tissue. Electromyography (hereafter referred to as EMG) is used extensively for clinical, kinesiological and bio-mechanical studies. Since the mid 1940's the development of more sophisticated apparatus and specialized recording systems have enabled the researcher to use EMG in the field of physical education.

Before the introduction of EMG, muscle function was studied through observation, topographic studies of dead muscles and calculations of what the muscle "ought to do" (1:24). Electrical stimulation, palpation of superficial muscles and the study of paralyzed patients are used readily in clinical fields. However, these methods have the primary limitation that they cannot adequately reveal the true function of the deep impalpable muscles nor can they record the exact sequence of contraction. Basmajian sums it up by saying that:

> It is not enough to estimate, by classical method, what a muscle can or might do. Electromyography is unique in revealing what a muscle actually does at any moment during various movements and postures. (1:25).

The qualities of EMG enable the researcher to study and analyze complex kinesiological movements. The exact timing and interrelationship of muscle group contractions during movement can be recorded permanently for detailed analysis.

EMG has also been used in an attempt to interpret the physiological complexity of muscular contraction. The intensity and duration of the contraction is indicated through a variation in the amplitude and frequency of the recording. As the contractions progress, muscular fatigue develops and the force of the contraction diminishes. The complexity of the fatigue phenomena is outlined by Astrand.

> Fatigue is a very complex conception, especially since heavy exercise, loads respiration and circulation as well as neuromuscular function. (2:86)

The fundamental purpose of this study is to observe fatiguing muscle contraction through the analysis of EMG recordings. A number of fatigue studies (3, 4, 5, 6, 7, 8) have been investigated since the inception of EMG. Each of these studies have dealt with the characteristics of the EMG recording during fatiguing contractions while performing a variety of isometric and/or isotonic contractions. Evidence has shown different relationships between the electrical potentials in muscle tissue and their variation over time. Edwards et al (9) and Eason (10) found a linear relationship between the integrated muscle action potential and the maintenance of a given tension under fatigue conditions. Lippold et al (11) and De Vries (12), however, indicated a curvilinear fatigue curve demonstrating a decrease in electrical activity followed by an increase at certain stages and loads during isometric exercise.
De Vries (12) suggests that the shape of the fatigue curve is open to question and a definite relationship between integrated muscle action potentials and time during fatiguing exercise is in need of clarification. This investigation will record the graphical relationship between three variables; integrated electrical activity, the degree of muscular contraction and the period of contraction during isometric and isotonic exercise. Surface electrodes are used to record EMG recordings

from the right rectus femoris muscle during static isometric contractions on a cable tensiometer apparatus and isotonic contractions on a weighted knee exerciser.

B. STATEMENT OF THE PROBLEM

The following problems are investigated:

1. To determine the rate of change in the level of integrated muscle action potential in the rectus femoris during varying degrees of maximum isometric contraction to the point of fatigue. The rate of change is indicated graphically using a fatigue curve to show the variation in integrated electrical activity over the time taken to fatigue.
2. To determine the rate of change in the level of integrated muscle action potential in the rectus femoris during isotonic contractions with loads at varying percentages of total body weight. The rate of change is indicated graphically using a fatigue curve to show the variation in integrated electrical activity over the time taken to fatigue.

A total of five males and five females between the ages of twenty and thirty years comprise the test group. Each subject attends eight exercise sessions over a period of four weeks. At each session one subject completes a series of isotonic or isometric muscular contractions to fatigue. The contractions are recorded on Kodak ultra violet sensitive paper. The readings show the normal EMG muscle action potential deflection pattern, an integrated recording of the EMG action potential and a measure of the tension exerted by the muscle during isometric contraction. The instrument used to record the readings is a Honeywell Electronic Medical System. The system contains a series of amplifying systems and recording apparatus appropriately designed to provide a permanent recording on paper. Input from adhesive surface electrodes applied to the muscle surface is fed into an Accudata 135 Biomedical Amplifier which produces a visual EMG recording. The EMG

recording is simultaneously integrated through an Accudata 136 Physiological Integrator. Muscle tension is recorded from a cable linked to a Baldwin Lima Hamilton Load Cell which is hooked through an Accudata 113 Bridge Amplifier. A Briston Dynomaster potentiometer linked through the bridge amplifier provides a visual aid for the subjects while holding isometric contractions at the specific percentage of voluntary contraction. Each of the three readings are recorded on a multichannel oscilloscope then onto paper in the Viscicorder Oscillograph 1912. The Viscicorder Oscillograph will provide a three channel trace from which observations and calculations will be made. The nature of the traces will constitute the bases for an analysis of the variation in integrated EMG as the muscle fatigues during specific levels of muscular contraction.

There are a number of limitations which should be taken into consideration in this study. The resolution power and recording capacity of the electronic equipment are primary limitations in a descriptive study of this nature. Individuals working to fatigue levels can be influenced by their psychological state at that time. Basmajian (13) discusses the variability in types of fatigue. Emotional fatigue, central nervous system fatigue, general fatigue and peripheral neuromuscular fatigue are all physical states which could effect the subject. Cramps, muscle soreness and general discomfort can contribute to a failure in performance. The delimitations of the test design, methods and procedures are evident. The study is based on readings from only one muscle, the rectus femoris of the right thigh. The subject numbers are limited to ten subjects between the ages of twenty-five and thirty and who exercise at least once a week. The percentages of voluntary contraction and the periods of contraction are based on the comfort of the subject. Each

subject will complete the isometric contractions with the leg extended to 115 degrees and there is no consideration given to individual limb sizes. The use of surface electrodes presents the disadvantage of uniformity in placement of electrodes on the muscle belly prior to each testing procedure. Individual variation in the nature and depth of the tissue superficial to the muscle may cause some variation in the level of electrical impulses picked up by the surface electrode. Due to the fatiguing nature of the tests each individual will suffer a certain level of pain. The level at which this pain will effect the muscular contraction will vary from individual to individual.

C. DEFINITION OF TERMS

Amplitude

A reference made to the EMG recording when referring to the height of the deflection above or below the base line.

Artifacts

A term used to denote any type of outside electrical interference which upsets the EMG tracing.

Deflection

The movement of the recorder which takes place during the recording of EMG. The deflection may be highly sensitive and fast or slower depending on what is being measured.

Fatigue

The condition of being very tired due to physical or mental exertion.

Frequency

Relates to the number of deflections recorded within a set space and time.

Integrated Muscle Action Potential

An electronic interpretation of the electrical activity in muscle tissue. The activity can be averaged or summated to give a more simplified recording of the complex EMG.

Isometric

Muscular contraction without any appreciable change in length. The term is synonymous with static contraction.

Isotonic

Muscular contraction in which the tension remains constant as the muscle shortens.

<u>Maximum Voluntary Contraction (MVC)</u>

The muscular contraction produced when a muscle is forcefully contracted to the subjects limit.

<u>Muscular Tension</u>

The degree of stretch within a muscle when it contracts against a force.

<u>Muscle Action Potential</u>

The electrical impulse recording produced from muscle tissue during contraction.

<u>Recruitment</u>

A physiological phenomena occurring during fatigue when additional fibres are stimulated to maintain a contraction.

<u>Summation</u>

The capacity of electrical impulses in muscle tissue to combine together to give a cumulative result from a series of contracting motor units.

<u>Trace Recording</u>

The electronic recording produced on a oscillograph from the movements of ultra violet light rays on light sensitive paper.

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CHAPTER II

REVIEW OF LITERATURE

Electromyographical diagnosis of muscle fatigue has been studied by a number of researchers who indicate great diversity in analysis procedure and final results. The physiological foundations of fatigue in muscle tissue are still not clear, making it difficult to diagnose the reasons for the different phenomena appearing in the electromyographic (EMG) recording. However, it has been shown that there are changes in the EMG recording as the muscle fatigues and as the muscle tension increases. Similarly it has been shown, using the integrated EMG recording, that there is a variation in electrical activity as the fatiguing process progresses.

The EMG recording has been analyzed in a number of ways by different workers in the field. The standard EMG recording can be studied and variations in the amplitude frequency and duration noted with respect to the type of muscular activity being performed. Each researcher in this review uses a different technique to analyze the EMG readings. However, each one is reporting on the variation in the EMG recording as the muscle is fatiguing during exercise. There is a need to clarify the various results presented in the area of EMG and fatigue. In general, most studies report an increase in EMG activity as the muscle fatigues under a given load when contracting isotonically or isometrically. However, there tends to be a considerable variation in the extent of decrease or increase in electrical activity as the muscle fatigues. When the results are represented graphically over time, a considerable

variation in curvilinear and linear relationships are demonstrated.

Edwards et al (1) studied isometric contractions of the gastrocnemius and investigated the relation between electrical activity and the tension of isometrically contracting human muscle under conditions of fatigue. Lippold's (2) dynamometer was used for a series of five second contractions ranging from nine to forty-five per cent of Maximum Voluntary Contraction (hereafter called MVC) with the electrical activity recorded during each contraction. A continuous contraction for four minutes at twenty-five per cent MVC was used to fatigue the muscle. The series of five second contractions was then repeated. The results indicated a linear relationship between tension and electrical activity during the initial part of the test. During the four minute fatiguing contraction there was a slight decrease in electrical activity during the first two minutes followed by an increase as the fatigue process progressed. The final part of Edward's Test indicated higher activity readings than in the first and middle stages, however, the linear relationship was maintained. Edwards (3) suggested that the muscle fatigue was brought about through a failure in the contracting process. The increase in electrical activity is a result of the recruitment of extra motor units to compensate for a decrease in the force of contraction. This theory is in agreement with Merton (4) and Bartley et al (5) who presented the theory of recruitment as being the cause of increased EMG during fatigue contractions.

Eason (6) studied the effects of sustained isometric contractions of the flexor digitorum sublimus on a hand dynamometer. The contractions were voluntarily maintained until exhaustion and were held at twenty-five, fifty and seventy-five per cent of MVC. The EMG

was analyzed on the basis of rate of change in magnitude, initial and final levels, average level and the total time a contraction could be maintained. The results indicated that the rate of increase in surface EMG readings was directly proportional to the magnitude of the contraction. The final and average EMG levels increased significantly when the contraction was increased from twenty-five to fifty per cent, however, stronger contractions had no significant effect.

The general result indicated that during a sustained contraction the surface EMG increased over time for every subject. The interpretation of these readings was based on studies of single motor unit activity. Lindsley (7) and Seyfforth (8) have shown that the height of the recorded deflection in the single motor unit decreased over time. Eason (9) suggested that this decrease reflected the failure of fatigued fibres within a given unit to fire, therefore, causing a failure in contraction. The gradual increase in amplitude demonstrated by Eason (10) suggested that additional motor units were being recruited to compensate for the loss in contractibility. The action potentials of the recruited fibres then summate with those already active to give a final EMG reading.

Sloan (11) investigated the fatigue pattern on an integrated EMG of the rectus femoris muscle during isotonic exercises for both general and local fatigue. The Harvard Step Test was used to cause the general fatigue. The Step Test caused cardio respiratory overload as well as muscular loading during the lifting of the body weight vertically. Local fatigue of the rectus femoris was developed by using leg extentions in the sitting position while wearing a weighted boot. The results indicated no apparent change in electrical activity

during the step up, and none of the subjects complained of lower limb fatigue. For the local fatigue test each subject lifted seventy-five per cent of his maximum which was attached to a weighted DeLorme boot. The results indicated a progressive increase in integrated activity for all subjects but one. A measurement of the amplitude increases varified the integrated reading increases. The frequency of the deflections showed no apparent increase.

De Vries (12) discussed the variation in experimental results based on the shape of the fatigue curve and the possible reasons for such variations. De Vries (13) also discussed the results presented by Edwards et al (14) and Lippold (15) indicating how electrical activity in the muscle can increase as a function of time and how the changing rate of work results in significantly different fatigue curves. De Vries (16) further suggested that the shape of the fatigue curve still appears to be open to question. Investigators such as Edwards et al (17) have found curvilinear relations under certain conditions. Other investigators such as Sloan (18) and Lippold et al (19) have demonstrated a basic linear relationship between electrical activity in the muscle during sustained muscular contraction. During pilot studies De Vries (20) reported curvilinear fatigue curves similar to Lippold et al (21) in about fifty per cent of the cases when the contraction was less than thirty per cent of the MVC. The remaining half of the subjects indicated a linear relationship. Fatiguing the muscle more rapidly with loads of eight per cent or more produced a greater proportion of linear plots.

De Vries's (22) study was designed to clarify the effect of the rate of work upon the relationship of electrical activity as a function of time in electromyographic fatigue curves. It was proposed to investigate the value of the slope of the curve or line as an objective

measure of the state of fatigue or muscular endurance. EMG recordings were taken with unipolor electrocardiogram (EKG) suction electrodes. The instrument used for EMG measurement of the right elbow muscle flexors was a hydraulically operated dynamometer connected to an electronic strain gauge which recorded the intensity of the contraction. A MVC was taken, then contractions were held for a maximum period of time at sixty, fifty, forty and thirty per cent of MVC. Sixty per cent was difficult to hold and therefore it was dropped. At fifty per cent MVC thirteen of fifteen subjects plotted a linear relationship. At forty per cent three of fourteen subjects showed an upward concavity toward the end of the run. However the first five plots were linear for all subjects. At thirty per cent MVC four subjects out of fifteen showed evidence of curvilinearity but again the first five plots were linear. EMG recordings were also taken for isometric fatigue and isotonic fatigue on the quadricep muscle group. In the isometric test three sessions at forty per cent MVC were maintained to maximum endurance time (MET) after one minute rest between each test. To test the possible variation due to aerobic effects in an isotonic contraction, knee extensor EMG recordings were taken after five minutes of step ups on to a seventeen inch bench at a rate of thirty steps per minute. The final graphical relationship for both the isometric and isotonic exercise was a linear one with increases in slope as the exercise period progressed.

Although the physiological causes for the increase in electrical activity is not the major aim of this study, De Vries (23) suggested two theories. Low threshold nerve fibres innervating the motor units produce small spike potentials, and higher threshold nerve fibres

produce the larger potentials in the muscle. Hugelberg (24), Buchthal et al (25) furnished evidence for the synchronization of motor unit potentials as the muscle is fatigued. The grouping and summating of activity gave rise to the increased electrical activity. De Vries (25) produced evidence that arterial occlusion can greatly increase the rise in electrical activity with respect to time.

Lippold et al (27) presented a total analyses of the EMG of fatigue. The changes in the size and form of the reading, the variation in integrated electrical activity and the effects of an arterial occluding cuff preventing recovery were dealt with in the study. The dynamometer used by Edwards (28) was the apparatus used for this study and silver surface suction electrodes were used to pick up the EMG impulses in the calf. A constant isometric tension was maintained on the dynamometer with the foot plantar flexed at a specific angle. At a constant tension the frequency of action potential spikes increased and the amplitude of the recording increased. The integrated activity with respect to the time increased gradually. At tensions between ten and eighty per cent of maximum, the integral of the electrical activity decreased slightly during the first one or two minutes but then increased to an end point five to ten minutes later. If the strength of the contraction was increased, the plotted curve was deeper and reached the end point faster. Lippold (20) plotted fatigue curves for the abductor digiti minimi muscle in the hand at weights of two, three and five hundred grams. As the weight increased so did the depth of the curve.

Scherrer et al (30) dealt with a variety of electromyographical analyses including summated or integrated EMG, oscillographic EMG and

elementary electrical activity of motor units. The particular area of study of interest here was the integrated EMG during isometric fatigue contractions of the triceps brachii. The load was set at twenty-five per cent of MVC and was held constant while integrated recordings were taken. An analysis of the integrated EMG was divided into a series of readings each demonstrating a different aspect of the result. The quantity of integrated electrical activity (Qmvt), the quantity of integrated electrical activity per unit of time (Qmvt/sec), the quantity of integrated activity per second during maximum effort of the subject (Qmax) and the integrated quantity during maximal effort per kilogram of force developed (Qmax-Kg) were examples of the analyses method used by Scherrer et al (31). Each set of data was graphed to produce a curve to indicate the variation over time. The general result of the changes in the integrated EMG during intensive isometric contraction indicated an increase relative to the mechanical performance accomplished.

The studies presented have indicated a variety of experimental techniques, applications and results. The results do demonstrate however, a need for a more definite relationship between the change in the characteristics of electrical muscle potential during fatiguing contractions.

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CHAPTER III

METHODS AND PROCEDURES

A. SUBJECTS AND MATERIAL

A sample of ten subjects selected at random made up the test group. Fifty per cent of the sample were females and fifty per cent males. The subjects ranged in age from twenty to thirty years and each exercised at least once a week. The subjects were advised to wear gym strips during the testing sessions to facilitate easy attachment of electrodes and comfort. Owing to the nature of the test objectives each subject was tested following little or no exercise during the day of the test.

The electrodes chosen to record the electromyogram were purchased through Hewlett Packard Medical Suppliers and Distributors. Each electrode was approximately two and one half centimetres in diameter and constructed from a silver metal disc set into a plastic insulating cup. (Figure 1). Each of the three electrodes had individual male leads, each with a plug appropriately colour coded to distinguish between the ground and the two recording electrodes. An eight foot, three wire, shielded lead, fitted with a female jack for the three electrodes was plugged into the rear of the recording system. To provide stability during subject movements the female jack was attached to a leather belt which could be removed and adjusted according to the size of the subjects' waist. The electrode leads were adjusted in length to provide freedom of movement during knee flexion and extension. The electrodes were attached to the subject using circular stick on discs which provided

SURFACE ELECTRODES

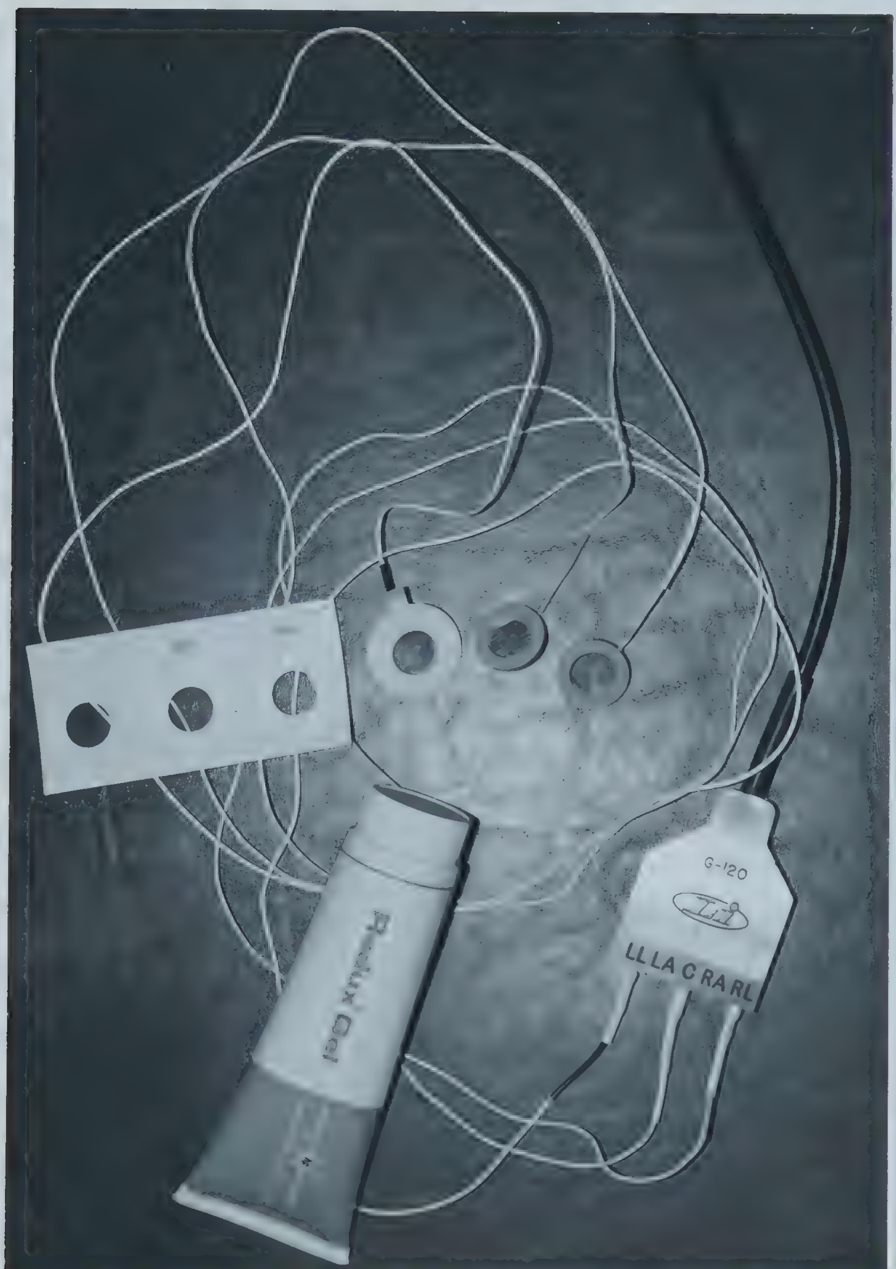


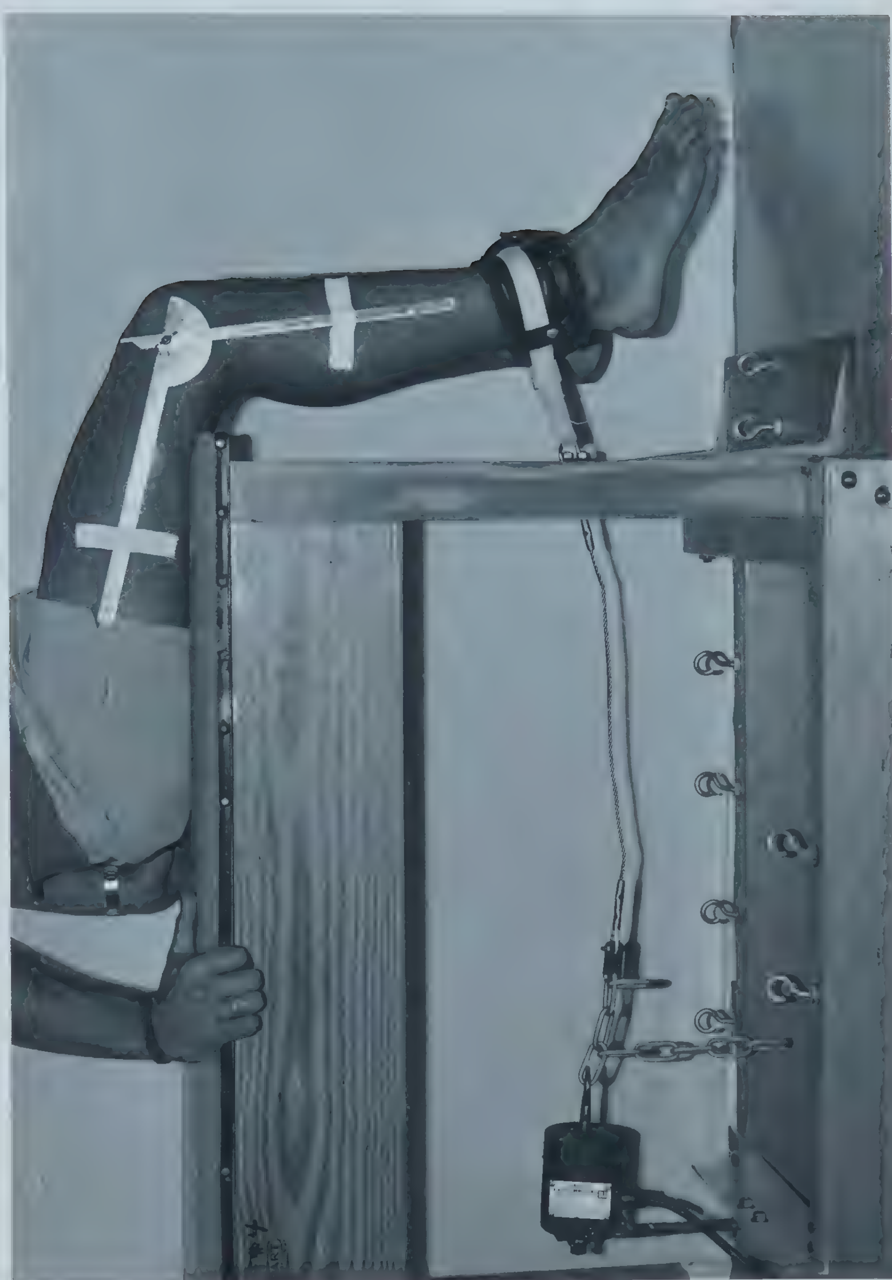
FIGURE 1

stability during movement and prevented the spread of electrode jelly from the inner cupped surface (Figure 1).

B. ISOMETRIC EXERCISE TESTING APPARATUS

A standard cable tensiometer test table was used with the subject seated with the legs flexed at the knee and positioned over one end of the table. An adjustable sling slid over the foot of the subject and tightened onto the lower leg. The sling was attached to a three foot long chain and a quarter inch steel tensiometer cable. The links in the chain provided the adjustment for each subject so that the leg was extended at a constant angle of one hundred and fifteen degrees (Figure 2). Padding was provided around the inside of the sling and behind the knee because pilot subjects complained of discomfort during long periods of exercise. The chain was attached to an electronic load cell which was mounted through a vertical iron bar and bolted to the base of the table. The load cell was positioned directly behind the right leg so that during the exercise the pull on the cell was linear. The load cell was manufactured by Baldwin Lima Hamilton Corporation and was equipped to take loads up to five hundred pounds. The gauge was constructed as an electronic transducer with a series of strain gauges electrically connected to form a bridge. The cell was equipped with a hook on one end which provided an adjustable attachment for the chain (Figure 2).

The test procedure involved the subject holding varying degrees of isometric contractions by extending the leg against the constant force of the cable. To provide the subject with a visual measure of the degree of contraction a clock type potentiometer was provided. The instrument was a Bristol Dynomaster Potentiometer equipped with



ISOMETRIC CONTRACTION TESTING APPARATUS

FIGURE 2

an eighteen inch circular dial numbered from zero to one hundred and forty. A large hand registered the level of the dial. The potentiometer was designed as a wind velocity recorder but was adapted for the purpose of this investigation. The dial was displayed in front of the subject and run off the output from the load cell and bridge amplifier in the main recording system (Figure 3). The amplification system for the load cell was provided through an accudata 113 Bridge Amplifier. The amplifier was designed to amplify signals from strain gauge bridge transducers and was equipped with normal sensitivity and balance adjustments. The potentiometer sensitivity was calibrated so that the dial registered the level of muscular contraction (Figure 3). To provide a contraction reading in pounds tension, the load cell was calibrated using standard metal weights placed in a container which hung from the cell in the vertical position. The readings recorded on the potentiometer dial were then converted into pounds tension (Table I).

BRISTOL DYNOMASTER POTENTIOMETER FOR ISOMETRIC CONTRACTION LOAD LEVELS

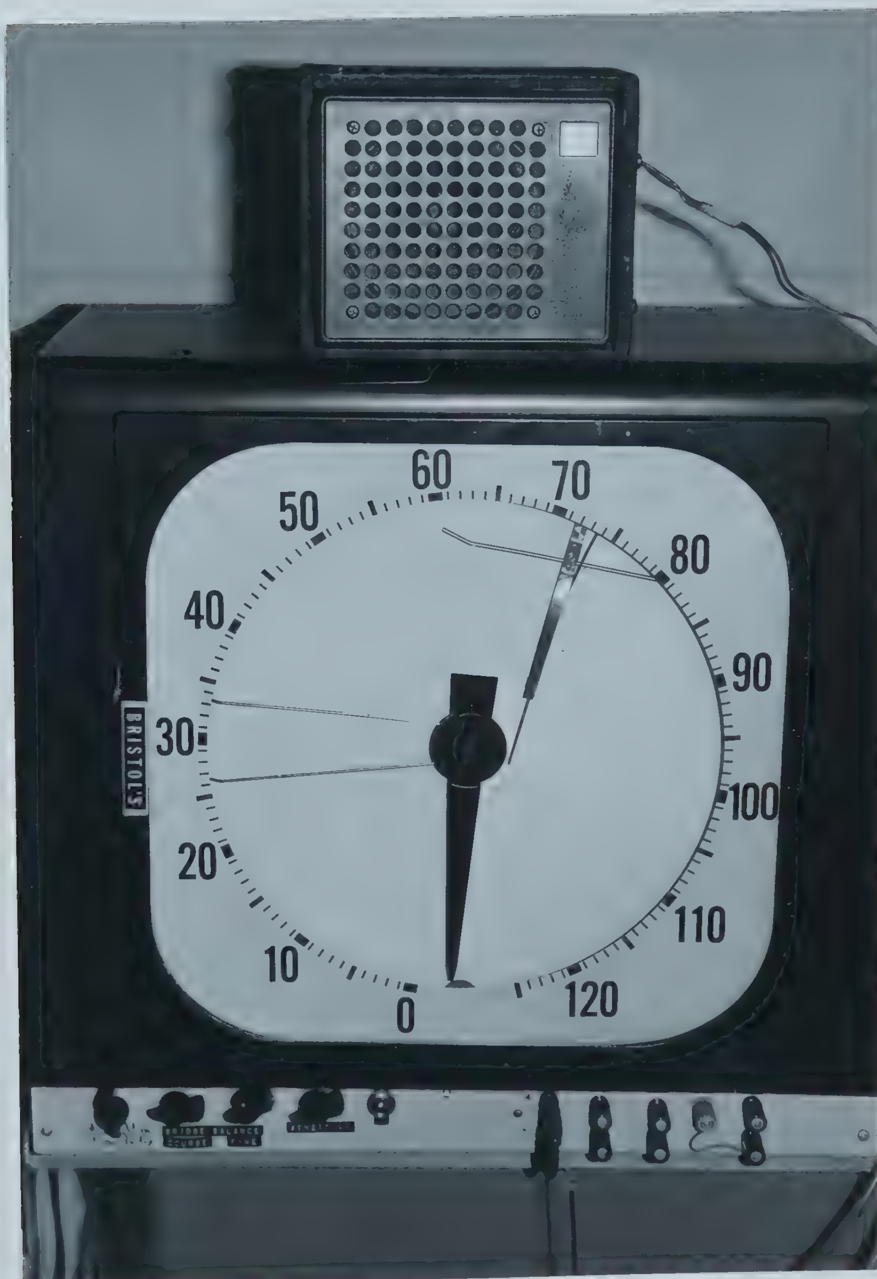


FIGURE 3

TABLE I

POUND EQUIVALENTS FOR POTENTIOMETER IN ISOMETRIC CONTRACTION TESTS

LBS.	POTENTIOMETER CHART READING	LBS.	POTENTIOMETER CHART READING
5	5	130	93
10	9	135	96
15	12	140	100
20	16	145	103
25	20	150	107.5
30	22	155	110
35	25	160	111
40	28.5	165	113
45	32	170	114.5
50	35	175	115
55	39	180	115.5
60	43	185	116
65	46	190	117
70	50	195	117.5
75	53	200	118
80	56.5	205	118.5
85	60	210	119
90	63	215	120
95	66.5	220	121
100	71	225	122
105	74.5		

TABLE I (continued)

POUND EQUIVALENTS FOR POTENTIOMETER IN ISOMETRIC CONTRACTION TESTS

LBS.	POTENTIOMETER CHART READING	LBS.	POTENTIOMETER CHART READING
110	78		
115	82		
120	85		
125	88.5		

C. ISOTONIC EXERCISE TESTING APPARATUS

The electrodes and electrode attachments used were identical to those used in the isometric test (Figure 1).

The testing apparatus for the test was a knee exerciser designed to provide leg extension at the knee with a one hundred and twenty degree range of movement. The weight loading for the exercise was governed by the addition or subtraction of metal weights from a swinging arm of the knee exerciser which is pushed forward on the anterior aspect of the lower leg during the extension to one hundred and eighty degrees. A padded seat provided comfort while the subject was strapped to the apparatus with a belt tightened across the upper thighs. A rubber pad attached to the weighted arm prevented bruising of the lower leg (Figure 4). The swing from the weighted arm of the knee exerciser was adjustable so that the subject could move the load through varying degrees. For this procedure the weighted arm was set so that the weight was carried from ninety degrees to full extension. An adjustable rod indicated the position of the large toe at full extension so that each contraction had to be maintained at that level. To provide standardization in the rhythm of the exercise a metranome was set at seventy-two beats per minute. Both light and audible timer provided the stimulus for each contraction. The total time of the exercise was recorded on a Gra Lab Universal Timer.

D. RECORDING EQUIPMENT

The system used to record results of the investigation was a Honeywell Electronic Medical System (Figure 5). The system measured and recorded physiological phenomena accurately and simultaneously. It consisted of seven visual recording channels with each channel

ISOTONIC CONTRACTION TEST APPARATUS

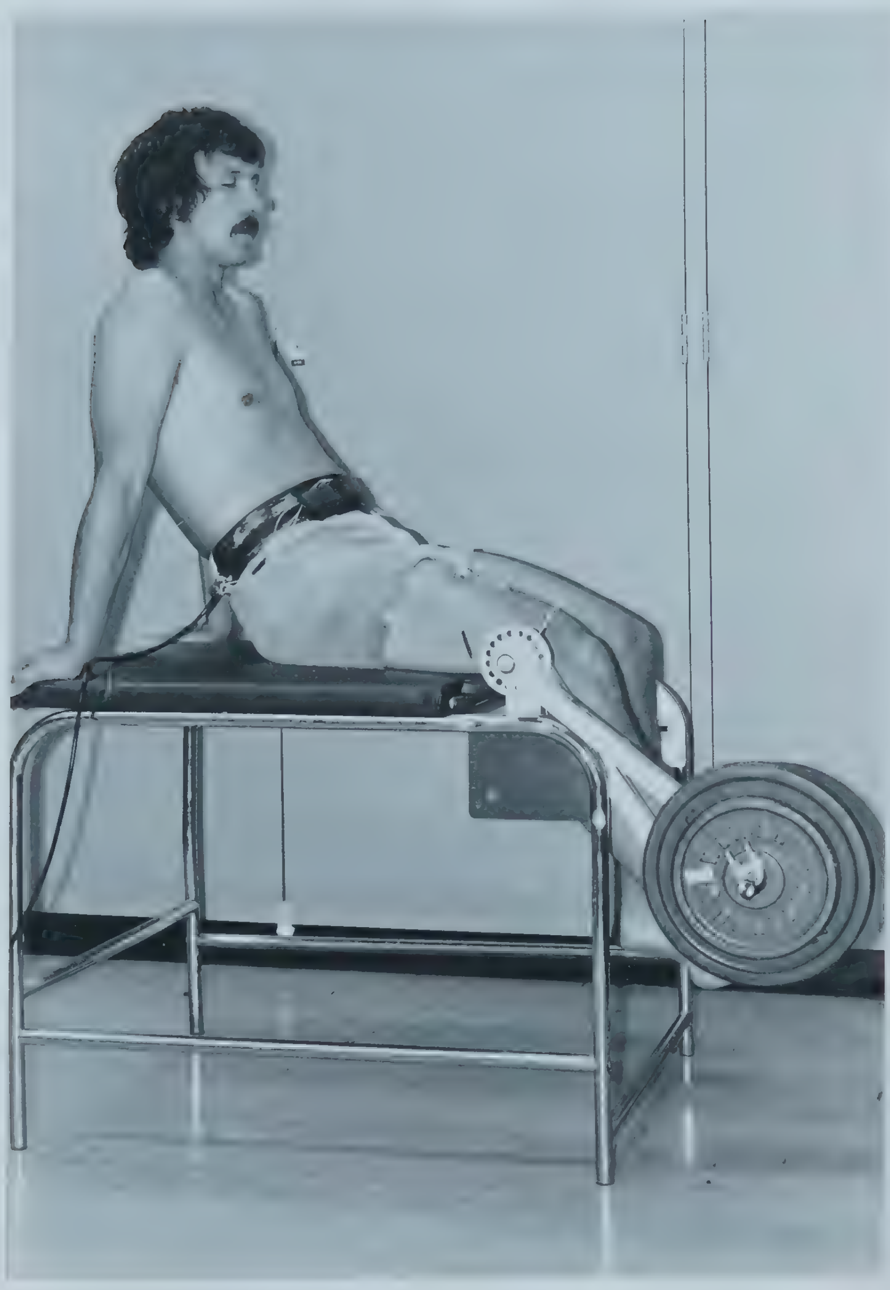


FIGURE 4

HONEYWELL ELECTRONIC MEDICAL SYSTEM

FIGURE 5

containing a transducer, electronic conditioning equipment and a recording or readout device. All the components of the system were set into a mobile metal rack assembly with the input panel for the input leads set into the rear.

Of the seven available channels in the system three were used for testing purposes in this investigation. Each channel included all the necessary components for making the specified measurement of a physiological phenomenon. Each channel consisted of a transducer or sensor to detect the pertinent phenomenon, a recording device, and electronics to condition the signal and make it compatible with the recording or display device. An EMG channel provided a clinically interpretable record of electrical activity in the muscle. The channel consisted of a set of three electrodes, an Accudata 135 Biomedical Amplifier and a galvanometer in an oscillograph. To provide a more amplified reading of the EMG the channel was equipped with an Accudata 136 Physiological Integrator. The integrator electronically collected the EMG output from the Accudata 135 Amplifier and integrated the electrical muscle potential to provide a visual reading on a multichannel oscilloscope plus a paper reading on an oscillograph. When the instrument was operating as an area summator the total electromyographical activity was recorded by producing an output proportional to the area under the EMG waveform. The integrator was therefore set to record the total area signified by "M" on the waveform switch. The instrument was calibrated and settings were made according to the manual.

A multichannel display oscilloscope, Model 8011 displayed the three channels simultaneously. The model accepted single ended, DC voltage and low frequency AC voltage inputs and displayed them at sweep speeds of ten, fifteen, twenty-five and one hundred mm. per second.

Sensitivity controls selected the individual inputs and varied the sweep readings. Each channel was individually controlled for waveform amplitude and vertical positioning. The Model 1912 Visicorder Oscillograph simultaneously recorded the three recordings. The oscillograph used a high intensity, ultra violet light source to record on ultra violet light sensitive paper. A high pressure mercury vapour lamp produced the ultra violet light that was reflected from the galvonometer mirrors through a precision optical system onto the recording paper. The oscillograph produced records on direct printout papers which developed with exposure to normal light (Figure 6).

E. DESCRIPTION OF PROCEDURES

Each of the ten subjects attended eight sessions, three for isometric and four for isotonic exercises and one introductory session. The seven sessions were randomly selected using the latin square method so each subject completed the tests in a different sequence and therefore minimizing learning and training effects (Table 2). Each subject completed the MVC test first so that individual percentages of MVC could be calculated. Body weights, then percentages of body weight for loading during the isotonic exercise were taken during the first exercise session. Each testing session was used to test only one subject and the same prepatory procedures were maintained. Each subject was time tabled to attend at approximately the same hour of the day and was scheduled so that the session was not immediately after exercise. The length of each session varied depending on the muscular endurance of each individual as each exercise was maintained until fatigue. Fatigue was defined as the condition of being very tired due to physical or mental exertion.

HONEYWELL VISICORDER WITH PAPER READOUT

FIGURE 6

TABLE II

SUBJECT NUMBER	TEST SEQUENCE 1	2	3	4	5	6	7	8
1	1	7	6	8	3	2	5	4
2	1	6	8	3	2	5	4	7
3	1	8	3	2	5	4	7	6
4	1	3	2	5	4	7	6	8
5	1	2	5	4	7	6	8	3
6	1	5	4	7	6	8	3	2
7	1	4	7	6	8	3	2	5
8	1	4	5	2	3	8	6	7
9	1	5	2	3	8	6	7	4
10	1	2	3	8	6	7	4	5

TEST NUMBERS		
1.	Weight and MVB	
2.	50% MVC	ISOMETRIC
3.	40% MVC	ISOMETRIC
4.	30% MVC	ISOMETRIC
5.	10% Body Weight	ISOTONIC
6.	15% Body Weight	ISOTONIC
7.	20% Body Weight	ISOTONIC
8.	25% Body Weight	ISOTONIC

The muscle selected for the study was the right rectus femoris, the most superficial member of the quadricep group on the anterior aspect of the thigh (Figure 7). The quadricep muscles are primarily flexors of the thigh and extensors of the leg at the knee joint. The three vasti muscles; lateralis, medialis and intermedius arise proximally from the shaft of the femur and attach distally into the patellar aponeurosis. The patellar aponeurosis continues as the ligamentum patella and attaches distally into the tibial tuberosity on the anterior proximal aspect of the shaft of the tibia. The rectus femoris or quadricep femoris muscle arises proximally from the ilium and ischium of the innominate bone and attaches distally with the three vasti muscles onto the patellar aponeurosis. The two heads of the rectus femoris muscle arise from the anterior inferior iliac spine of the

RECTUS FEMORIS MUSCLE

FIGURE 7

ilium and the reflected head from the superior aspect of the acetabulum of the innominate bone. The muscle belly of the rectus femoris is superficial and visible during contraction as it lies between the vastus lateralis and vasties medialis (Figure 7).

The skin surface over the muscle was shaved to remove any hair then lightly rubbed with fine glass paper. The surface was then cleansed with alcohol to provide a good adhesive surface for the electrodes. The positioning of the electrodes on the muscle belly was standardized for each subject so that placement of each electrode at the commencement of the exercise session was identical in each of the seven sessions. For electrode positioning an imaginary line was taken to dissect the muscle. The line extended from between the two heads of the rectus femoris proximally to the medial border of the patella distally. When in the seated position with slight contraction against the cable tensiometer cable the rectus femoris muscle belly was visible (Figure 7). The centre of the muscle belly was found by measuring approximately half way between the anterior superior iliac spine and the supero medial edge of the patella. Two permanent ink spots were made three centimetres either side of the centre mark and in the centre of the muscle belly. The ink marks were used for the centering of the two active electrodes and the ground electrode was placed over the tibialis anterior muscle on the anterior aspect of the leg (Figure 8).

The physiological EMG integrator calibration was checked by reacting the level of integration reset control at different levels and stimulating the electrodes. The resulting recordings indicated that for every one unit on the recording paper the integration metre measured two millivolts. Calibrations were repeated before each testing procedure so that integration levels were consistent throughout the testing programe.

PLACEMENT OF SURFACE ELECTRODES

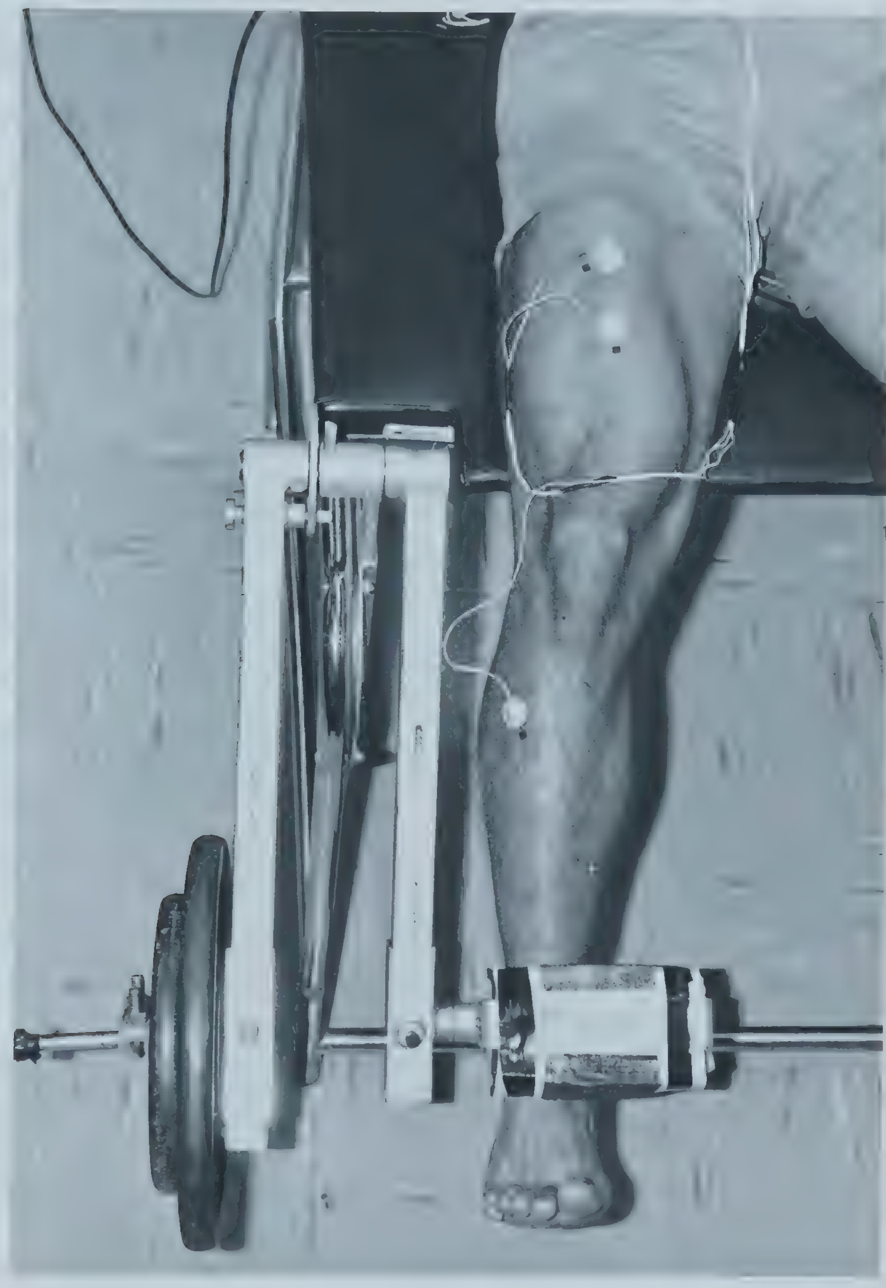


FIGURE 8

F. TESTING PROCEDURE FOR ISOMETRIC CONTRACTION

Each subject was seated on the end of the cable tensiometer table; knees slightly apart; trunk slightly angled back; and the hands gripping the edge of the table. All contractions were carried out with the leg extended to an angle of one hundred and fifteen degrees. Pilot studies were run on three subjects to obtain the angle of maximum tension (Figure 2). The one hundred and fifteen degrees is set with a goniometer and the adjustment made on the chain so that the leg was extended at the required angle when the chain was held taut. A record was kept for each subject to indicate the link number on the chain and therefore each test was completed at the same angle. The isometric contraction was achieved by extending the leg to the limit of the chain with the quadriceps contracted against the static force of the load cell fixed to the base of the tensiometer table. Rubber padding was provided inside the sling and under the right knee to prevent discomfort during the exercise.

The testing sessions for the isometric tests were completed in random sequence with the isotonic tests but on different days (Table 2). The test sessions were:

1. Explanation of test procedure, orientation to testing apparatus and MVC tests.
2. Fifty per cent contraction. - isometric
3. Forty per cent contraction. - isometric
4. Thirty per cent contraction.- isometric

A sixty per cent contraction test was removed from the test programme as the pilot subjects indicated difficulty in holding the tension. In the initial session the subject was shown the apparatus and recording

equipment and an explanation was given on the objectives of the investigation. The subjects' weight and height were taken so that the isotonic loadings could be calculated for the tests to follow (Table 3). The skin surface over the right rectus femoris and proximal aspect of the right tibialis anterior was prepared for future electrode attachments. The details of this procedure were explained earlier in this chapter. Semi-permanent markings were made on the skin over the muscle belly and the subjects were instructed not to remove them. The angle of the knee joint for the isometric contractions was measured with a goniometer and the cable tensiometer adjusted to maintain an angle of one hundred and fifteen degrees (Figure 2). The leg sling was adjusted to slip over the subjects foot and the padding adjusted for maximum comfort. The posture desired during the test was explained previously and the subjects attempted a number of small contractions so that they were accustomed to the dial reading on the potentiometer and the general feeling of the sling. A series of four MVC were then recorded with a two minute break between each contraction. The mean recording of the four MVC was then taken as the MVC from which percentages of contraction were calculated for the remaining isometric tests.

The percentage contractions for the isometric exercises were fifty, forty and thirty per cent of the MVC. The calibrated measure in pounds tension was provided for the subject so that he was aware of the amount of weight he was supporting during the exercise (Table 4). Each session for an isometric test involved holding a contraction at one of the three percentage readings for as long as possible. As soon as the needle on the dial dropped below the required point the subject ceased the contraction. The electrodes were attached at the commencement of the session using the procedure explained earlier and tracings were

TABLE III

SUBJECT PERCENTAGE LOADING FOR
ISOTONIC TESTS

SUBJECT	SUBJECT WEIGHT POUNDS	PERCENTAGE BODY WEIGHT			
		10%	15%	20%	25%
1	132	13	20	26	33
2	115	12	17	23	29
3	115	12	17	23	29
4	111	11	17	22	28
5	156	16	23	31	39
6	206	21	31	41	52
7	152	15	23	30	38
8	165	16	25	43	41
9	215	21	32	43	54
10	206	21	31	41	52

TABLE IV

SUBJECT PERCENTAGE LOADINGS FOR ISOMETRIC TESTS

SUBJECT NUMBER	MAXIMUM VOLUNTARY ISOMETRIC CONTRACTION POUNDS	PERCENTAGE OF MAXIMUM VOLUNTARY ISOMETRIC CONTRACTION 30%	40%	50%
1	170	51	68	85
2	191	57	76	95
3	147	44	58	73
4	147	44	58	73
5	125	37	50	62
6	125	75	50	62
7	123	74	49	61
8	120	36	48	60
9	165	50	66	62
10	121	36	48	60

recorded during the contractions. A basic EMG recording and an integrated EMG recording was recorded during the contraction. The integration was set to integrate EMG recordings every ten seconds and the subject was instructed to start each contraction when the integrator was on zero. A tension recording was also taken through the load cell and strain gauge bridge amplifier. The total contraction time was recorded on the Gra Tab Universal Timer which was turned on at the beginning and off at the end of each contraction. The recordings were analyzed for the drawing of fatigue curves relating the variation in integrated EMG activity over the period of contraction (Figure 9).

G. TESTING PROCEDURE FOR ISOTONIC CONTRACTION

The subjects were prepared for the attachment of electrodes in the manner discussed previously. The electrodes were attached over the markings on the surface of the rectus femoris after the skin surface was prepared. The subject was seated on the knee exerciser in a comfortable position and the electrode lead lengths adjusted to prevent them from interfering with the equipment. A belt was tightened across the subjects thighs to prevent him from raising the trunk during exercise. The weighted arm on the knee exerciser was adjusted so that the arm moved through ninety degrees to a point where the leg was fully extended. A bar was adjusted so that the large toe of the extended foot was level with it (Figure 4). The contraction exercise was finished when the subject was unable to reach the bar. A metronome was set in front of the subject during the exercise.

The isotonic exercise involved the continuous flexion and extension of the leg at the knee while forcefully pushing a swinging weighted arm during the extension phase. The weighted arm was equipped with a

PAPER READOUT RECORDING FOR ISOTONIC CONTRACTION

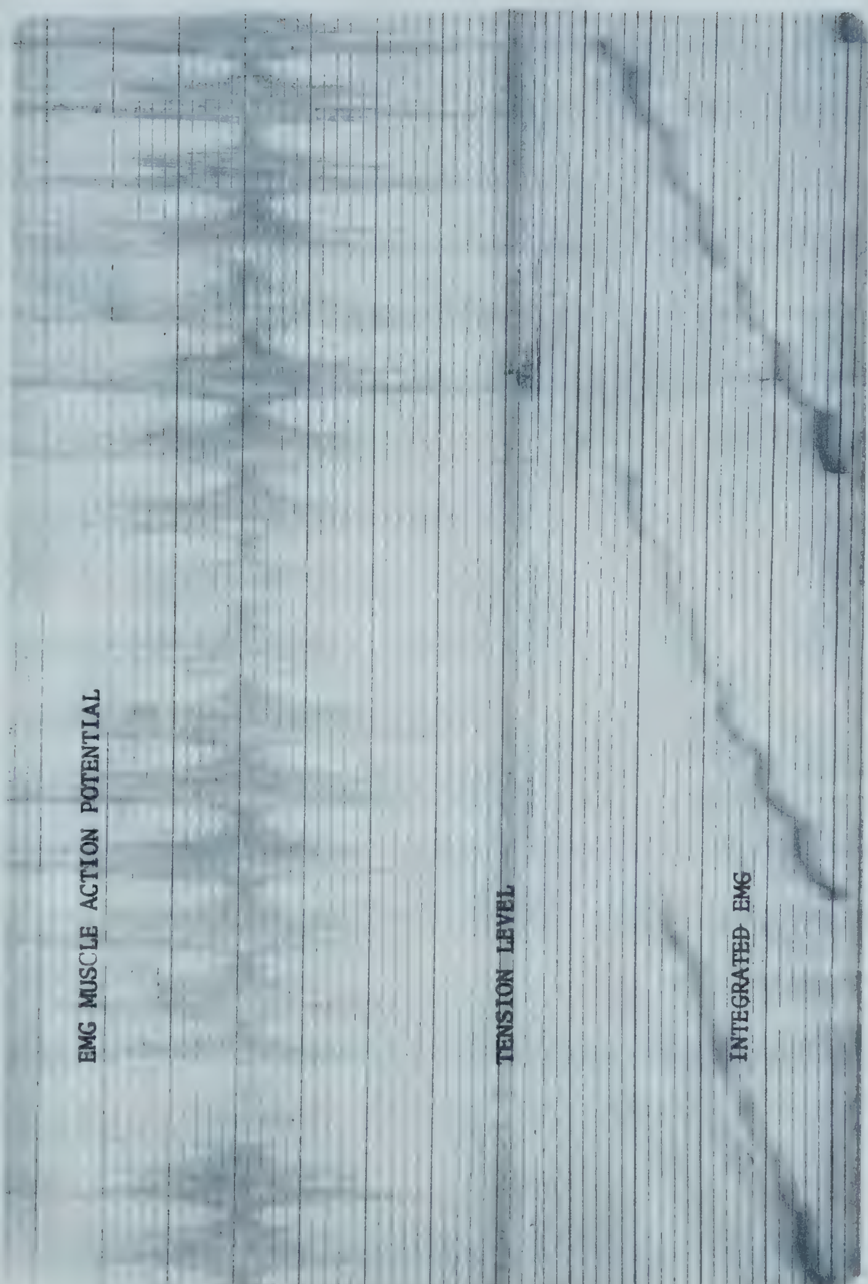


FIGURE 9

rod, over which standard metal weights were suspended. During each isotonic contraction session the weight loading was a percentage of the subjects total body weight which in this case was ten, fifteen, twenty or twenty-five per cent (Table 3). The contractions were maintained to the rhythm of a metronome set at seventy-two beats per minute. The contraction sequence involved three stages from rest to extension then back to rest. Each contraction from rest to rest took three rhythm beats on the metronome. The subject, therefore, completed twenty-four contractions per minute. The contractions were continued until the subjects' quadriceps were fatigued and incapable of extending the leg to the height of the bar.

The isotonic test sessions were:

1. ten per cent body weight.
2. fifteen per cent body weight.
3. twenty per cent body weight.
4. twenty-five per cent body weight.

Each session was attended in random order with the isometric tests (Table 2). Two tracings were recorded; the basic EMG and the integrated EMG.

The total period of isotonic contraction was timed on the Gra Tab Universal Timer so that the variation in the integrated EMG trace was represented over time.

Each recording sheet was marked with the subjects name and number together with the details, type of test performed and the period of contraction.

H. STATISTICAL TREATMENT

The statistical treatment used for this study was a one way analysis of variance run on each of the seven tested variables. The analysis of variance (anova) programme was run for each ten second period over the total testing time for each variable. The results indicate the relationship between each of the tested variables from one ten second time period to the next. Means were computed from the electrical activity recorded each ten seconds for each isotonic and each isometric test. For each ten second period a significant (F) factor was computed. If this reading indicated a significant difference between the means, the Newman-Keuls Comparison between Ordered Means was used to indicate how the means differed and which means differed from each other.

A file of raw data was constructed (Appendix A) to represent the recordings taken in each of the tests taken by the ten subjects. A table was constructed, giving the time period, means, variance and standard deviation for each of the isotonic and isometric tests (Appendices B and C). The statistical data in these tables was used to construct a graphical representation of the variation between each tested variable over time. Tables are presented to indicate, sum of squares, mean square, degrees of freedom, significant (F) and probability ratio for each anova (Appendices D and E).

CHAPTER IV

RESULTS AND DISCUSSION

A. RESULTS

(a) MEAN AND RANGE VALUES FOR AGE, WEIGHT AND HOURS OF ACTIVITY PER WEEK

The means and range values for age, weight and hours of activity per week for the ten subjects are given in Table V.

TABLE V

	MEAN X	RANGE
AGE (YEARS)	26.5	25 - 29
WEIGHT (POUNDS)	157.3	111 - 215
ACTIVITY (HOURS)	6.9	4 - 12

(b) TIME INTERVAL VARIATIONS FOR ISOTONIC CONTRACTIONS

Each isotonic contraction test was tested for the variation in integrated electrical activity over the time period for the contraction. A one way analysis of variance was used to indicate the degree of difference between each level of isotonic contraction at each ten second stage of the test. The raw data on each subject is shown in Appendices B, C, D and E. The results of the isotonic tests are given in Table 6.

The table gives the time period for the contraction, the significant F reading at the 0.05 level and the significant differences between the means at each percentage level of contraction. The Newman-Keuls Comparison between ordered means was used for the mean comparison (Table 6).

TABLE VI

ISOTONIC CONTRACTIONS - SIGNIFICANCE LEVELS

TIMES (SECONDS)	F (0.05)	NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS					
		10-25	10-20	10-15	15-25	15-20	20-25
0- 10	4.10	*	*	-	-	-	-
10- 20	6.62	*	*	-	-	-	-
20- 30	6.71	*	*	-	*	-	-
30- 40	8.27	*	*	*	-	-	-
40- 50	9.01	*	*	-	*	-	*
50- 60	13.74	*	*	-	*	-	*
60- 70	7.55	*	*	-	*	-	*
70- 80	7.55	*	*	*	*	-	*
80- 90	3.79	*	-	-	-	-	-
90-100	2.75	0	-	-	0	-	0
100-110	3.61	0	*	-	0	*	0
110-120	5.73	0	*	-	0	*	0
120-130	2.38	0	0	-	0	0	0
130-140	2.03	0	0	-	0	0	0
140-150	.10	0	0	-	0	0	0
150-160	2.22	0	0	-	0	0	0
160-170	3.96	0	0	-	0	0	0

* SIGNIFICANT AT THE 0.05 LEVEL

0 PERCENTAGE LEVEL OF CONTRACTION HAS DROPPED OUT DUE TO FATIGUE

\- NO SIGNIFICANT RELATIONSHIP

(c) TIME INTERVAL VARIATIONS FOR ISOMETRIC CONTRACTIONS

Each isometric contraction test was tested for the variation in integrated electrical activity over the total time period for the contraction. A one way analysis of variance was used to indicate the degree of difference between each level of isometric contraction at each ten second stage of the test. The raw data for each subject tested is shown in Appendix C . The results of the analysis of variance are shown in Table 7 . The table gives the time period for the test, a significant F reading at the 0.05 level and the significant difference between the means at each percentage level of contraction. The Newman-Keuls Comparison between ordered means was used for the mean comparison.

(d) GRAPHICAL RELATIONSHIP BETWEEN MEAN INTEGRATED EMG AND TIME FOR ISOTONIC CONTRACTION

Statistical data for each percentage level of isotonic contraction is given in Appendix B. Time period, mean, variance and the standard error of the mean are shown. The variation between the mean recordings for integrated EMG and the ten second time periods is represented in graphs one, two and three. Each of the four percentage levels of contraction, ten per cent, fifteen per cent, twenty per cent and twenty-five per cent are indicated on each of the three graphs. Each graph records the variation in mean integrated EMG levels over seven ten second intervals and for each of the percentage contractions. The heavier percentage contractions will conclude at different time intervals indicating the fatigue point.

TABLE VII

ISOMETRIC CONTRACTION - SIGNIFICANCE LEVELS

TIME (SECONDS)	F (0.05)	NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS		
		30-50%	30-40%	40-50%
0- 10	2.19	-	-	-
10- 20	3.55	*	-	-
20- 30	4.64	*	-	-
30- 40	3.30	*	-	-
40- 50	4.66	*	-	*
50- 60	7.52	*	-	*
60- 70	6.20	*	-	-
70- 80	3.92	*	-	-
80- 90	2.55	0	-	0
90-100	35.72	0	*	0
100-110	15.15	0	*	0

* SIGNIFICANT AT THE 0.05 LEVEL

0 PERCENTAGE LEVEL OF CONTRACTION DROPPED OUT DUE TO FATIGUE

\- NO SIGNIFICANT RELATIONSHIP

(e) GRAPHICAL RELATIONSHIP BETWEEN MEAN INTEGRATED EMG AND TIME FOR ISOMETRIC CONTRACTION

Statistical data for each percentage level of isometric contraction is given in Appendix C. Time period, mean, variance and standard error of the mean are shown. The variation between the mean recordings for integrated EMG and the ten second time intervals is represented in graph four. Each of the three percentage levels of contraction thirty per cent, forty per cent and fifty per cent are indicated on one graph. The graph records the variation in mean integrated EMG levels over the total contraction period for each of the three percentage contractions. The heavier percentage contractions will conclude at different time intervals indicating the fatigue point.

At the lower contraction levels a minimum number of subjects maintained their contractions for longer than the level indicated in the graph (Graph 4). Due to the small number (n) a truly representative mean could not be calculated for that time interval. As the total time period for the contraction was not a major consideration, mean integrated EMG values were calculated up to the point where the majority of the subjects were sustaining a contraction.

B. DISCUSSION

(a) CONSIDERATIONS AND LIMITATIONS IN THE DISCUSSION OF EMG FATIGUE RESULTS

An effective discussion of the results should involve the consideration of a number of subjective psychological and physiological observations and concepts. These observations may or may not have an effect on the subjects performance. Researchers should attempt to standardize or minimize these limiting factors in future fatigue studies.

The concept of fatigue and the associated effects are complex problem areas and are difficult to control and measure. Mental fatigue based on tension, lack of sleep or over work could have an influence on the concentration level of the subject. Central nervous system fatigue and neuromuscular fatigue have been discussed by Basmajian (1) and is an important consideration. The level of neuromuscular fatigue prior to the start of testing is difficult to measure. For example, it was not known to what degree a subject may have fatigued during the walk to the lab or during the ascent of the stairs up to the lab immediately prior to each test. The initial EMG readings may have therefore been effected. An attempt was made to minimize these effects by limiting the amount of physical exertion during the twenty-four hours prior to testing. The subject relaxed for at least ten minutes prior to the test in an attempt to minimize the possible psychological tensions which may have existed. Controlling the subjects every day activities prior to testing was almost impossible. Individual occupations placed different physical and mental demands on each individual. In one subject work load and emotional demands varied to an extent which could have effected initial EMG readings and the total period of contraction.

Individual differences in the ability to function under stressful conditions can be exemplified in pain threshold. The measurement of an individuals pain threshold is dependant on many variables. Pain threshold may be involved in the testing of fatiguing muscular contraction especially when it is tested over an extended period to the point of complete exhaustion. Some subjects may have terminated their contraction due to neuromuscular pain threshold.

Although each subject had an average physical activity schedule, a number suffered from post exercise muscle tightness and general soreness of the quadricep muscle group. Maximum efforts may have been limited by the retested subjects who knew that more discomfort had to be tolerated. However, it was observed that after the initial exercise, soreness symptoms were far less acute during the subsequent tests. It was also interesting to note that the individuals who exercised a greater number of hours per week suffered very few or no side effects from muscle soreness. In the subjects who experienced muscle soreness the symptoms were concentrated around the patella aponeurosis, the distal attachment of the quadriceps muscle group. Difficulty in walking and in ascending stairs was a general complaint.

The surface electrodes used to pick up the muscle potential from the rectus femoris were chosen on the basis of comfort, easy placement for retesting, and because of the superficial nature of the muscle tested. However the question must be asked as to whether we are only testing the rectus femoris or are we also testing the fatigue processes in the three vasti muscles lying deep, medial and lateral to the rectus femoris? Were the EMG recordings primarily from the rectus femoris over which the electrodes were centered or were the recordings the result of a summated cross talk (electrical muscle potential recordings

from adjoining muscles) effect? The variability in each individual's tissue properties between the muscle belly and the electrode should be an additional consideration. The thickness and density of the tissue overlying the rectus femoris varied from one subject to the next. For example the qualities of adipose tissue may effect the electrical muscle potential reading picked up by the surface electrode. The thickness and nature of the skin layer may also have an effect.

Individuals react differently under stressful conditions and their performance may vary depending on the type of motivational stimulus to which they are subjected. During the testing procedure an attempt was made to standardize the verbal and mechanical stimuli as much as possible. The Gra Tab timer was placed in a position where the subject could see the length of time period for his contraction. Verbal stimulation was kept to a minimum, however, each subject was asked to contract at a specific load level for as long as he or she could possibly hold it.

These are some of the considerations involved in the EMG testing of muscular fatigue.

It is important to note that when athletes are performing under stressful conditions there are a number of variable conditions which could be effecting neural and muscular control. These limiting variables were controlled as much as possible in the laboratory testing situation. The variables which cannot be controlled effectively must be carefully considered when analysing the results of fatiguing muscular contraction.

(b) ISOTONIC AND ISOMETRIC CONTRACTION TO FATIGUE

The relationship between time and mean integrated EMG is best indicated as a curve in Graphs 1, 2, 3 and 4. Each curve represents the mean integrated EMG for every ten seconds of contraction at each percentage level of MVC over the total period of the contraction.

All of the isometric and isotonic contraction curves indicate an increase in integrated EMG as the contraction period increases. The heavier the contraction the greater the slope of the line (Graphs 1, 2, 3, 4) and the shorter the contraction period. The curves demonstrate steeper and shorter lines for the high load contractions. The electrical activity required to maintain a greater load is more than that of a lesser load. The period of contraction is shorter for heavy loads than it is for low percentage loads. This indicates that, the greater the contraction the greater the final electrical activity level required to maintain the contraction. Although electrical activity is present in the final stages contraction cannot be maintained.

The assumption can be made that although the electrical impulse is high during the final stages of fatigue contraction the muscle is unable to maintain its tension. The effect of neurological impulses on the fatigued muscle is such, that it cannot bring about the contractile process. The failure point for contraction occurs sooner during heavy percentage load levels (Graphs 1, 2, 3, 4).

It appears that electrical potential is necessary to bring about the physiological changes which are necessary for muscular contraction. The physiological conditions, however, become exhausted to a point where neurological stimulation no longer has an effect. During heavy contractions the physiological functioning of the muscle cells are under greater

electrical stimulation even immediately before the contraction was ceased. As a result the rate of increase in stimulation is proportional to the load and tension of the muscle (Graphs 1, 2, 3 and 4). The greater the percentage load of MVC the greater the demand for electrical stimulation.

The reasons for the phenomena reported here has been suggested by Lindsley (2) and Seyfforth (3). The increases in electrical activity are related to the recruitment of additional motor units. The increased electrical activity stimulates additional muscle fibres so that the contraction level can be maintained. The heavier the contraction, the greater the demand for additional fibres. The additional fibres which provide the increased tension must be continually recruited as each one fatigues. The level of contraction or tension necessary for the lower percentage loads is less and requires less recruitment of additional fibres. The level of recruitment therefore, is less at thirty per cent than it is at fifty per cent.

It appears that in the final stages of fatigue the electrical activity is still increasing (Graph 4), however, the muscle cannot maintain its tension. Although the electrical stimulation is present the muscle fails to maintain its tension due to some other physiological failure. It appears that fatigue is not attributed to neurological failure but due to a failure of the neural stimulus effecting contraction within the muscle cell.

There are a number of noticeable fluctuations in the thirty per cent and fifty per cent isometric curves (Graph 4). The thirty per cent curve shows a noticeable decrease at ninety seconds then a considerable increase. Although not as severe, the fifty per cent curve indicates a similar decrease, then an increase at the sixty second point. The forty

per cent curve remains linear. The reason for this variation in linearity may be related to the consistency of the neural stimulation. The decrease is due to a decreased demand for electrical stimulation, as the muscle can maintain its tension without additional motor unit recruitment. The subsequent increase is due to a greater demand to maintain the tension level at each specific load.

The demand for muscular stimulation tends to be variable in the two extreme load levels, thirty per cent and fifty per cent. However, the demand is regular at the forty per cent level. The regularity of electrical stimulation at the forty per cent level indicates a consistancy which could prove significant in the training and learning process. Extremely heavy contractions create fluctuation due to the great demands placed on the muscle. Extremely light contractions also indicate a fluctuation in electrical stimulation. Perhaps this is due to both a lack of demand on the muscle and an irregular demand for extra recruited fibres.

Lippold (4) indicated a decrease in integrated EMG during the first two minutes of fatigue exercise in the plantar flexas of the leg. There was no indication of any decrease at any percentage level of isometric contraction in this study. Edwards (5) indicates progressively higher integrated EMG readings during fatiguing contractions and showed a similar linear relationship. Eason's (6) study on a sustained isometric contraction of the flexor digitorum sublimus indicated a rate of increase in EMG proportional to the magnitude of contraction. The contractions were at twenty-five per cent, fifty per cent and seventy-five per cent of MVC and each level increased linearly. Sloan (7) reported an increase in integrated EMG during a seventy-five per cent of MVC test on the rectus femoris. However, the variation in increase

was not discussed in this study, therefore, the linearity or curvilinearity was not considered. During pilot testing, De Vries (8) showed a curvilinear relationship between integrated EMG and time when contracting below thirty per cent of MVC. Only fifty per cent of the subjects indicated this curvilinearity while the remaining fifty per cent had a linear relationship. None of the subjects in the study indicated a decrease at any percentage of isometric contraction. De Vries (9) also indicated a linear relationship for isotonic and isometric contractions at forty per cent and at higher load levels of contraction.

The significant relationships between each percentage loading of isometric contraction at each time interval are shown in Table VI. The thirty per cent and fifty per cent contractions show a significant relationship at the 0.05 level at all stages of the contraction, except the first ten seconds. This indicates that the muscle requires more electrical stimulation during the total fatigue contraction at the fifty per cent level than at the thirty per cent level, but the stimulation required to initiate the contraction is not significantly different. The difference between the thirty per cent and forty per cent contraction was not significant at any time interval until the final stages when a difference was shown at the 0.05 level.

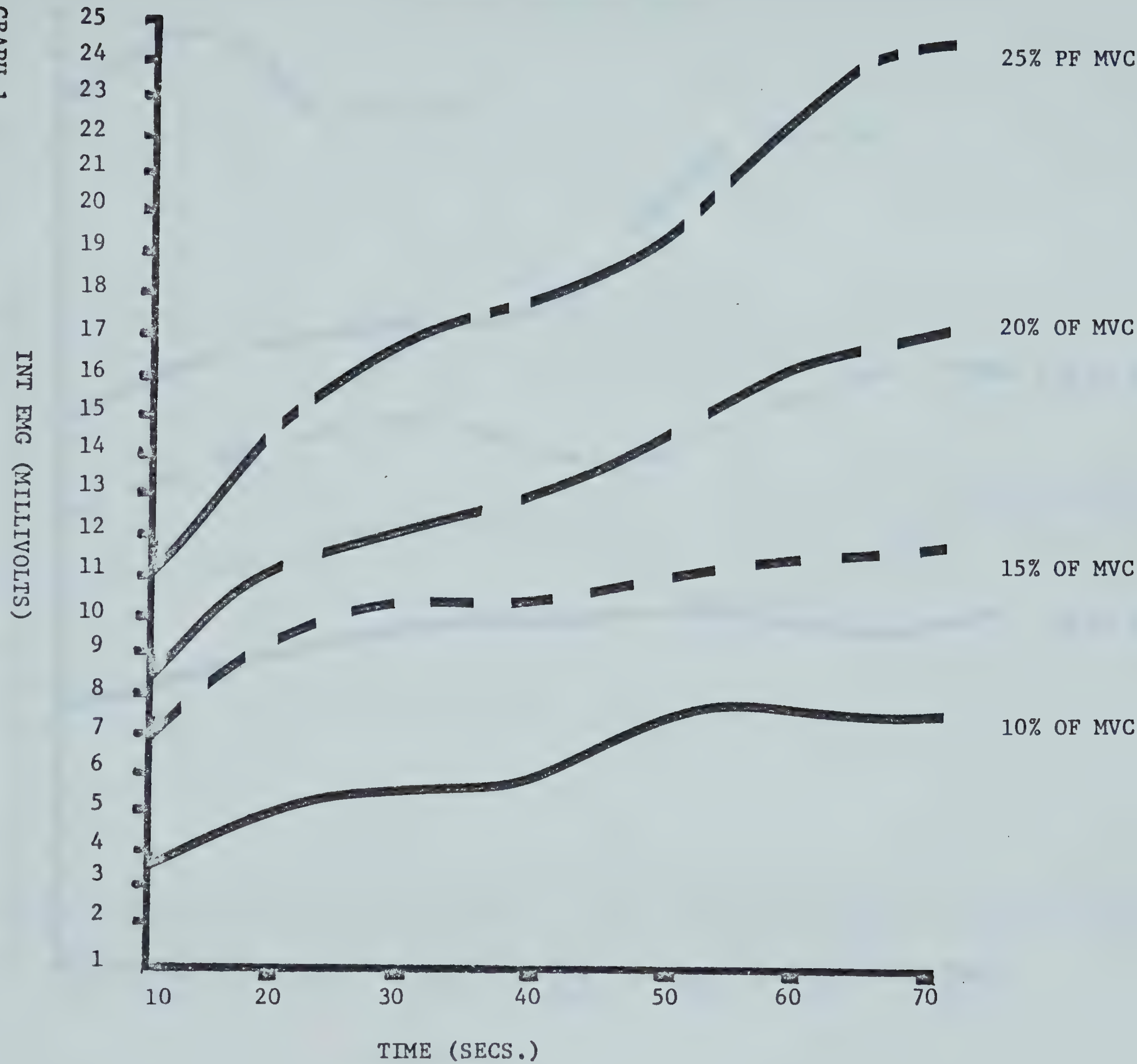
The greatest difference between all percentage load levels occurs during the final stages of fatigue contraction. The requirements for motor unit recruitment are proportionally greater as the load level increases. Lindsley (10), Seyfforth (11) have suggested that the proportionally greater demand for neural stimulation is due to the recruitment and summation of muscle fibres. Graph 4 has indicated three linear increases in integrated EMG over time. The forty per cent load showed no fluctuation in neural stimulation but the thirty per cent and fifty

per cent curves indicate considerable variation.

The application of these results to a physical training or work situation could be tested through a further study. The study would be designed to detect the differences in muscular performance due to training at a forty per cent load level and at thirty per cent and fifty per cent load levels. Constantly increasing neural stimulation may in fact be more beneficial to the training athlete as the fatigue process occurs. However, the results have indicated these facts during isometric contraction. The activity would therefore have to be closely related to static muscular contraction where a percentage of MVC could be gauged and tested.

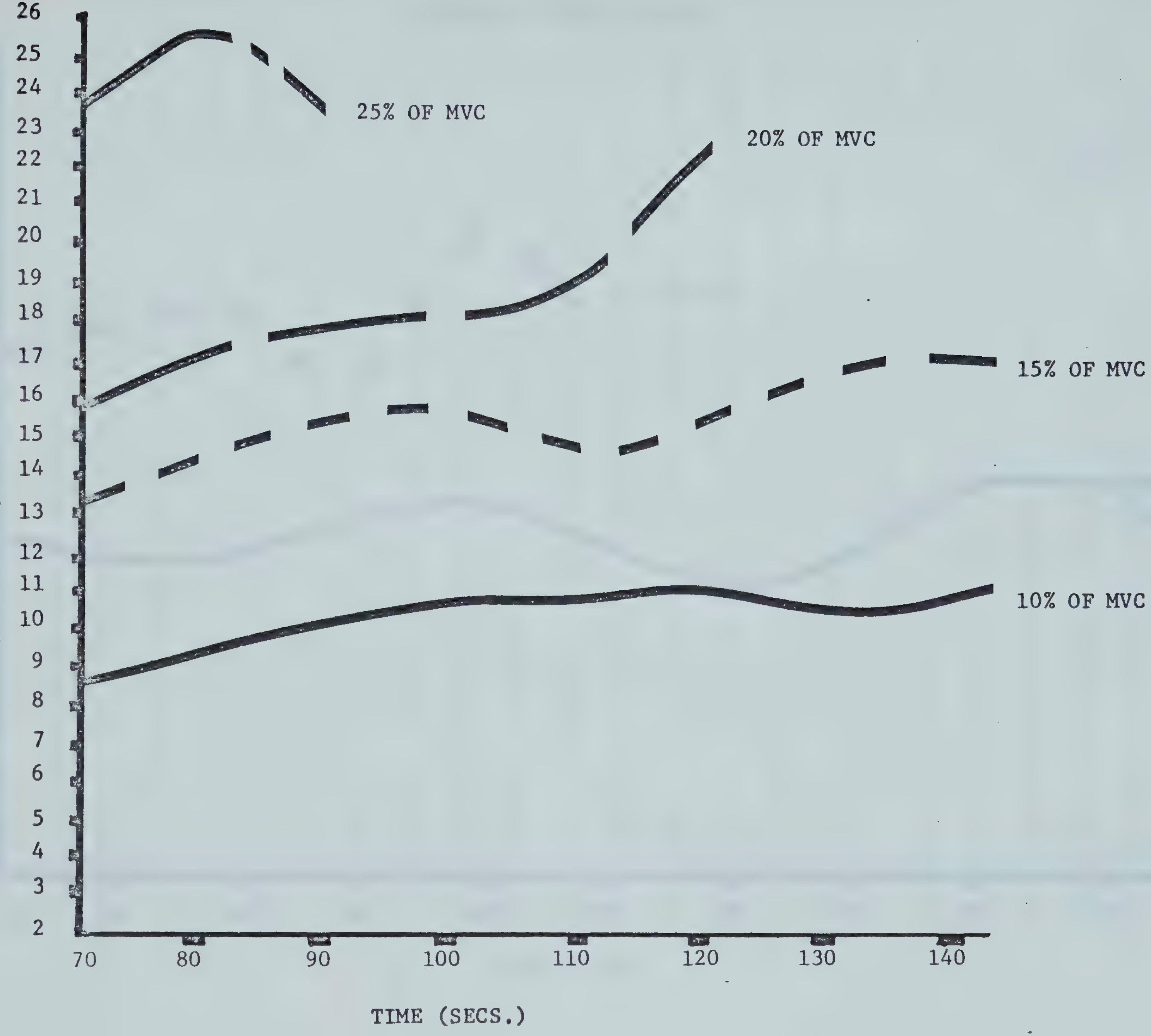
The relationships between integrated EMG and time during the four percentage load levels of <u>isotonic contraction</u> indicates a degree of linear fluctuation (Graphs 1, 2 and 3). Each of the four loads, ten per cent, fifteen per cent, twenty per cent and twenty-five per cent indicate proportional increases in integrated EMG during the total contraction. Variations in EMG tended to appear to a greater extent in the two lowest loads, ten per cent and fifteen per cent and the highest load twenty-five per cent. A degree of fluctuation was evident in each of the loads other than the twenty per cent level (Graph 1, 2 and 3). The theory put forward by Lindsley (12) and Seyfforth (13) relating to the summation and recruitment of fibres during fatigue contractions explains the increases in neural stimulation. However, the fluctuations are not explained. The heavier the contraction loading the greater the demand for neural stimulation and the shorter the total contraction period. It appears that the heavier the contraction the greater the demand for additional neural stimulation so that additional motor units can stimulate more fibres and so maintain the contraction. All the load levels increase over the first

ISOTONIC FATIGUE CURVES



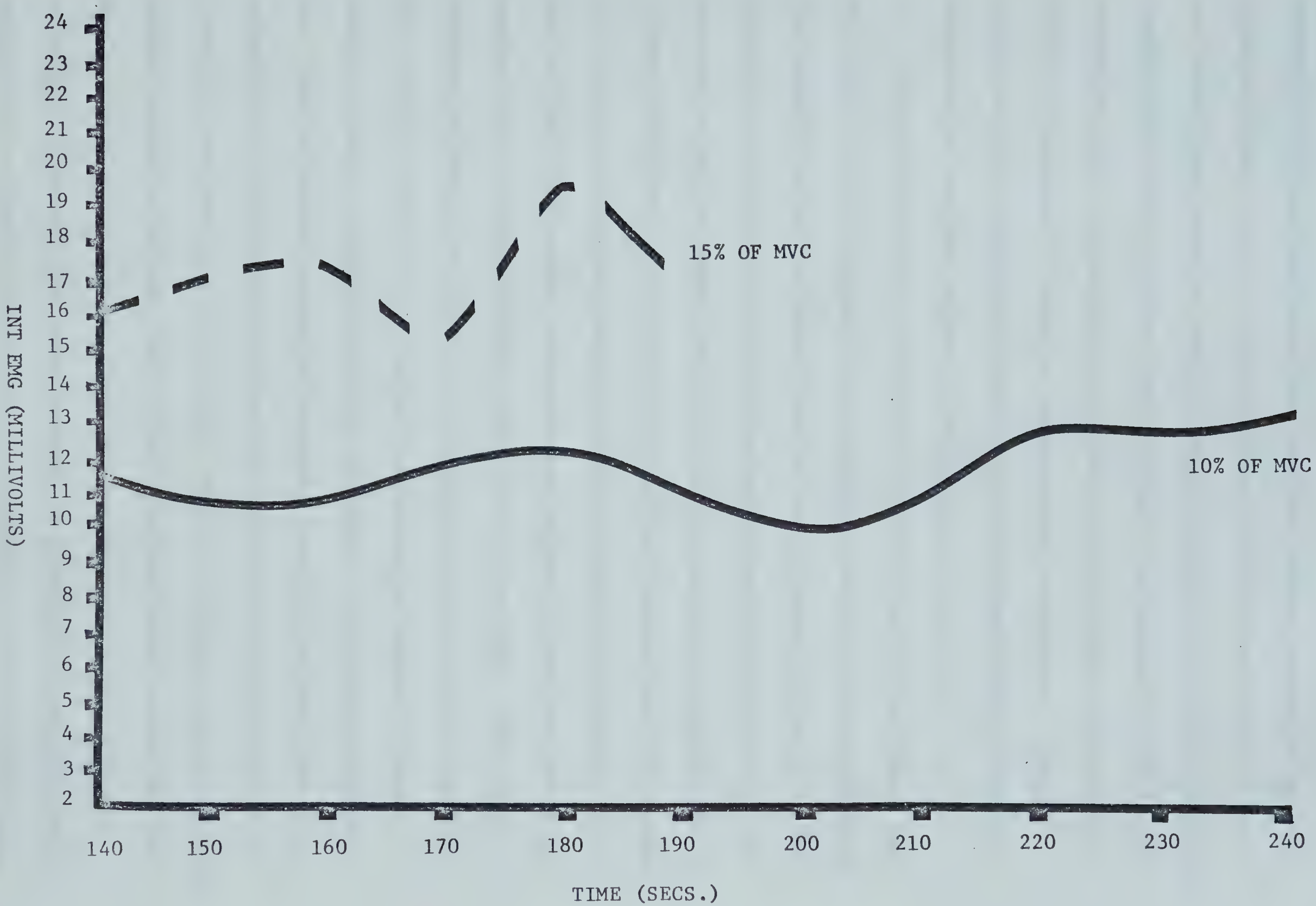
GRAPH 1

ISOTONIC FATIGUE CURVES



GRAPH 2

ISOTONIC FATIGUE CURVES



GRAPH 3

seventy seconds and similarly over the next seventy seconds up to 140 seconds (Graph 1 and 2). The two highest contractions finish at comparitively high levels of EMG, the twenty per cent contraction increasing considerably during the final ten seconds. The decrease in EMG level during the final ten seconds of the twenty-five per cent contraction cannot be explained in terms of summation and recruitment. The EMG levels on all the other load levels of isotonic contraction indicated increases in the final stages of contraction (Graph 2).

The fluctuations in linearity are evident in the two lowest contractions, ten per cent and fifteen per cent, and to a lesser degree in the highest contraction twenty-five per cent (Graphs 1, 2 and 3). The twenty per cent contraction indicates no fluctuation in EMG level. The increase in EMG is comparitively regular increasing at a steady rate to a level equivalent to the twenty-five per cent contraction. It appears that the recruitment and summation process suggested by Lindsley (14) and Seyfforth (15) occurs with much more regularity when the muscle is contraction isotonically with a load of twenty per cent. The neural stimulation during the ten per cent, fifteen per cent and twenty-five per cent load levels is not regular and appears to demand different levels of EMG to maintain tension in the muscle. The results indicate that there is a more regular and constant flow of electrical muscle potential at a twenty per cent level of isotonic contraction (Graph 1, 2 and 3). The question is, does this regularity signify a more efficient contraction mechanism and, would it be more beneficial to exercise the muscle at the twenty per cent level of isotonic contraction during training? It appears that more research is necessary to show how muscle contractile performance varies due to training at different percentages of MVC. It is unclear in the literature as to the significance and

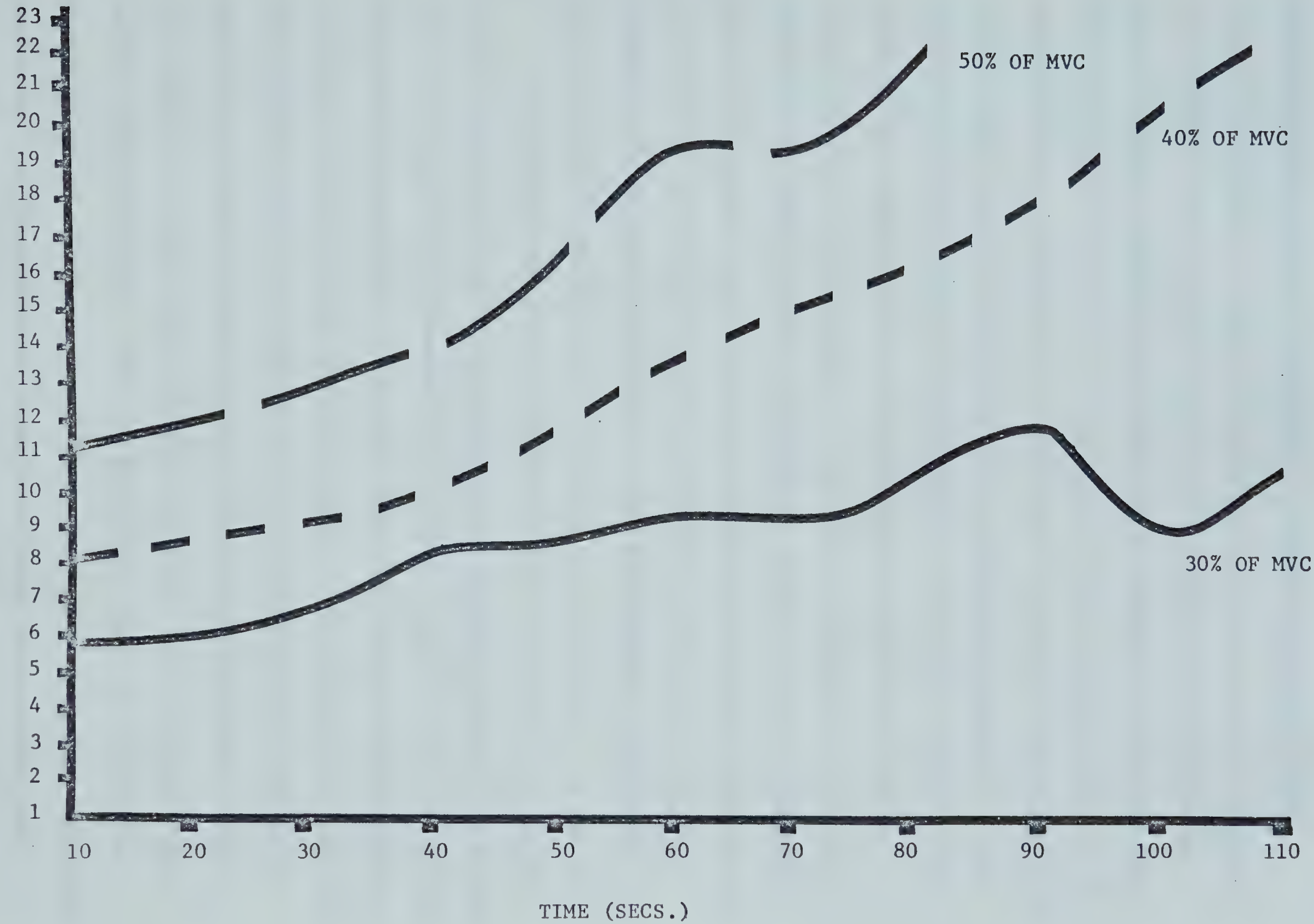
importance of the level and variation of muscle action potential during the isotonic contraction fatigue process.

The literature did not report any fluctuations in isotonic fatigue curves, but studies refer to the curvilinear or linear curve relationships. Sloan (16) reports an increase in integrated EMG during isotonic exercise with a weighted Delorme boot however, the shape of the curve is not discussed. De Vries (17) tested for a variation in aerobic type isotonic contraction and isometric contraction. The relationship between integrated EMG and time for both the aerobic test and the isometric test indicated linear increases. Scherrer (18) reported increases in integrated EMG relative to the mechanical performance accomplished but did not discuss any variability in the curve.

The significant relationships between each percentage loading of isotonic contraction at each ten second time interval are shown in Table V. The relationships indicated in the table are at the 0.05 significance level. Differences are shown between the lightest and heaviest isotonic contractions during the total contraction period. Significant differences are indicated between ten per cent and twenty-five per cent, between ten per cent and twenty per cent. Similar differences are shown between fifteen per cent and twenty-five per cent more so toward the middle and last stages of the contraction period. The variation in slope in Graphs 1, 2 and 3 also indicates the different levels of integrated EMG required during the contraction period. There is little or no difference shown between ten per cent and fifteen per cent or between fifteen per cent and twenty per cent as the slope of the curves are similar and both curves fluctuate to a greater degree toward the end of the contraction period.

Differences in EMG levels occur when the difference in load

ISOMETRIC FATIGUE CURVES



GRAPH 4

percentage contraction is ten per cent or more than ten per cent. When the difference is less than ten per cent no significant difference is indicated. For example a significant difference is shown between ten per cent and twenty-five per cent but not between ten per cent and fifteen per cent (Table V). The exception to this observation is in the high loads when differences are shown between twenty per cent and twenty-five per cent during the last half of the contraction (Table V). The difference in this instance is demonstrated by the graph lines in Graph 1 and 2. The twenty per cent load increases are smooth and linear indicating a consistant demand for electrical stimulation. The twenty-five per cent load fluctuates considerably during the entire contraction period. It appears that the heavier contraction causes an inconsistency in demand for electrical stimulation and the muscle does not receive a steady inflow of electrical impulse. This also appears in the lower contraction loads ten per cent and fifteen per cent (Graph 1, 2 and 3).

In summary, the levels of integrated EMG increased in proportion to the contraction load in both <u>isotonic</u> and <u>isometric</u> tests. The greater the load the greater the demand for electrical stimulation and the shorter the period of contraction. The level of EMG at the point of fatigue was, in all but one case, higher than at any other time during all the isotonic and isometric tests. The indication is that contractile failure is not due to lack of neural stimulation but a failure at the cellular level. The demand for neural stimulation at the cellular level is proportional to the contraction level. When the contraction fails at the cellular level the neural stimulus is still maintained. Contraction is maintained during the test through neural stimulation which recruits additional motor units, which in turn, summate with fibres already contracting. Lindsley (19) and Seyfforth (20). The contraction fails when the

muscle fibres fail at a cellular level even though the electrical stimulation can still be recorded at a high level.

A fluctuation in demand for electrical stimulation is evident in the extreme percentage loads during both isotonic and isometric tests. The forty per cent isometric test showed an almost perfect linear relationship with little fluctuation in EMG levels. The twenty per cent isotonic test also indicated a consistant linear relationship with far less fluctuation in demand. The relevance of consistency in EMG levels during fatigue contractions is not indicated in the literature and could be pursued as a follow-up study. The changes and variations in EMG levels during the fatiguing process has yet to be correlated with the changes at the cellular level.

When considering the results discussed in this chapter it is important to relate to the limitations and complexities involved in neuromuscular fatigue studies.

Astrand sums it up by saying that:

> "Fatigue is a very complex conception, especially since heavy exercise loads respiration and circulation as well as neuromuscular function." (21:86)

The relationships between EMG levels and muscular fatigue are a part of the complex physiological phenomena of fatigue. More research is necessary to simplify and understand these concepts so that training methods for the athlete can be improved and better understood.

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CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Electromyographical recordings were taken from the skeletal muscle of ten human subjects, fifty per cent of whom were female. Each subject attended eight testing sessions on different days over a period of four weeks. The order of testing for each of the eight sessions was based on a random selection of latin square method. The test sessions involved one introductory test to measure the vital statistics for each individual. The remaining seven testing sessions measured electromyographical muscle potentials in the rectus femoris muscle during isometric and isotonic contractions to the point of fatigue. The level of contraction during each test was based on a percentage of the measurements taken in the initial session. The point of fatigue was considered the point after which the subject could not complete or maintain a contraction at the specified level.

The parameters measured during the testing procedure were recorded on permanent paper recordings and the data was taken from those recordings. The parameters measured included: EMG muscle potential, tension level during isometric tests, integrated EMG and the total time period of the test. The relationship between integrated EMG and time was indicated in the analysis of the results using a fatigue curve. The variation in slope at different levels of isometric and isotonic contraction was discussed. Also discussed were the significant differences between the different levels of contraction at different time intervals during the contraction.

The reasons for the increase in EMG in the muscle was discussed with reference to the literature and standard physiological concepts. The fluctuation in electrical stimulation during different levels of contraction was discussed with reference to training and learning patterns.

All percentage levels of both isotonic and isometric muscular contractions indicated a proportional increase in EMG levels. The reasons for the increases were related to the recruitment of muscle fibres and the summation of electrical potential within the muscle. It was noticeable, however, that although the EMG level continued to rise and maintain its level, the muscle contraction failed. It was concluded that the contractile failure occurred as a result of physiological failure within the muscle cell and not to lack of neurological stimulation.

Fluctuating levels of EMG were evident in the lowest (thirty per cent) and highest (fifty per cent) <u>isometric</u> load levels. It was concluded that these fluctuations were related to an inconsistency in recruitment resulting in a change in the total summated level of electrical activity. There were no fluctuations indicated in the forty per cent isometric contraction. The suggestion is that a regular recruitment and summation pattern may be beneficial to a training athlete. The regular pattern appears only at the forty per cent level for isometric contraction. Further research is necessary to validate this finding.

Fluctuating levels of EMG were evident in the lowest (ten per cent, fifteen per cent) and highest (twenty-five per cent) <u>isotonic</u> load levels. There were no fluctuations in the twenty per cent level of isotonic contraction. The regularity of recruitment and summation during the twenty per cent level of contraction may be beneficial for the training muscle.

B. CONCLUSION

As a result of the tests performed it can be stated that integrated EMG levels in the rectus femoris muscle increased proportionally with the percentage load level of isometric and isotonic contractions. It was also shown that although neural stimulation was present in the muscle the contraction failed at the point of fatigue. Muscular fatigue was therefore, said to occur physiologically at the cellular level and not due to a lack of neural stimulation. We can also conclude that the level of integrated EMG fluctuates at different stages and at different load levels of isometric and isotonic contraction. These fluctuations are a result of irregular neurological stimulation due to the variable demands placed on the muscle during exercise. The regularity of neural stimulation controlling the recruitment of muscle fibres has been suggested as a possible controlling element in the training of muscle. This regularity appears during twenty per cent isotonic and forty per cent isometric contraction. Studies using training programmes which exercised muscle at loadings of twenty per cent isotonic and forty per cent isometric would clarify these findings.

Many athletes train at sub maximal and maximal levels. According to present research it is questionable as to which level of sub maximal training is more beneficial for the conditioning and development of human muscle. EMG fatigue curves in this study have indicated a consistency in recruitment and summation patterns at certain sub maximal levels of contraction.

More extensive research is necessary to clarify the use of EMG as a measurement of muscular performance. The regularity and functioning patterns of muscle fibre recruitment and the effects of fatigue contractions provide a strong source for the understanding of muscular fatigue.

C. RECOMMENDATIONS

Muscular fatigue is a limiting factor in virtually all physical performance activities. The neural stimulation which is measured through the EMG of the contracting muscle can provide a greater understanding of the complexities of fatigue. As a result of this investigation a number of recommendations may prove helpful.

(1) Investigations should be developed using different muscle groups but the same procedures as were used in this study. It may result that different muscle groups have different fatigue patterns.

(2) Investigations should be made into sub maximal training programmes for athletes. Different levels of sub maximal muscular contraction could be used in training programmes and the variations in the EMG fatigue curve noted.

(3) A study could be developed to use the EMG fatigue curve as a fitness parameter.

(4) Further investigations should look at the effects of isokinetic exercise on EMG in fatiguing muscle.

(5) More information is required to assess the training effects of the various mechanised weight training systems eg. Nautilus, Mini Gym, Universal.

(6) There is more research necessary on the development of an effective telemetry system for the measurement of EMG during the competitive situations.

(7) Various methods of recovery from fatigue are used by the athlete. The effectiveness of these methods should be looked at and measured in terms of the effect on the EMG pattern before and after the recovery method used.

(8) An investigation should be made into the effects on the EMG pattern due to a stretching and flexibility muscle training programme.

(9) One of the disadvantages of using needle electrodes is the difficulty of replacement in the identical region of the muscle for a re-test. A study should be developed to test the feasibility of using needle electrodes in test re-test studies.

(10) The properties of the skin and underlying tissue have an effect on surface electrode readings. A study should be designed to show the relationship between per cent body fat and the resultant surface EMG readings from the underlying muscle.

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APPENDIX A

SUBJECT PERSONAL DATA

SUBJECT NUMBER	AGE (YEARS)	WEIGHT (POUNDS)	AVERAGE HOURS ACTIVITY PER WEEK	OCCUPATION
1	25	132	6	STUDENT
2	26	115	5	NURSE
3	27	115	4	TECHNICIAN
4	27	111	4	NURSE
5	25	156	5	STUDENT
6	25	206	10	STUDENT
7	29	152	8	STUDENT
8	26	165	12	STUDENT
9	27	215	10	STUDENT
10	28	206	5	LABOURER
MEANS	26.5	157.3	6 - 9	
RANGE	25 - 29	111 - 215	4 - 12	

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX B

ISOTONIC CONTRACTIONS 10%

TIME (SECONDS)	MEAN (X)	VARIANCE (s^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	3.8	5.9	2.4
10- 20	4.5	5.6	2.4
20- 30	5.1	9.6	3.1
30- 40	4.9	7.2	2.6
40- 50	7.0	17.7	4.2
50- 60	7.1	21.0	4.6
60- 70	7.0	58.0	7.6
70- 80	8.0	58.4	7.6
80- 90	8.4	53.2	7.3
90-100	8.8	52.17	7.2
100-110	9.0	46.9	6.8
110-120	9.3	45.6	6.8
120-130	9.1	51.6	7.2
130-140	9.3	57.5	7.5
140-150	9.9	59.6	7.7
150-160	10.4	64.52	8.0
160-170	8.3	20.5	4.5

ISOTONIC CONTRACTIONS 15%

TIME (SECONDS)	MEAN (X)	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	7.7	21.5	4.6
10- 20	8.8	20.8	4.5
20- 30	10.2	26.8	5.1
30- 40	10.1	21.2	4.6
40- 50	10.6	18.9	4.3
50- 60	10.9	24.9	4.9
60- 70	12.2	42.8	6.5
70- 80	12.7	38.2	6.1
80- 90	13.6	50.7	7.1
90-100	14.3	46.5	6.8
100-110	12.6	11.4	3.3
110-120	13.3	12.6	3.5
120-130	14.6	18.8	4.3
130-140	15.25	21.5	4.6
140-150	11.3	.3	.5
150-160	18.0	31.0	5.5
160-170	15.3	57.3	7.6

ISOTONIC CONTRACTIONS 20%

TIME (SECONDS)	MEAN (X)	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	9.4	10.3	3.2
10- 20	10.7	11.5	3.4
20- 30	11.7	12.9	3.5
30- 40	12.3	15.1	3.8
40- 50	14.3	26.9	5.2
50- 60	16.0	30.5	5.5
60- 70	16.6	29.3	5.4
70- 80	17.5	35.9	6.0
80- 90	18.3	38.6	6.2
90-100	18.6	64.3	8.0
100-110	19.3	65.3	8.0
110-120	24.0	32.0	5.6
120-130			

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ISOTONIC CONTRACTIONS 25%

TIME (SECONDS)	MEAN (X)	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	10.2	41.2	6.4
10- 20	14.7	70.4	8.3
20- 30	16.2	86.4	9.2
30- 40	17.2	82.4	9.0
40- 50	19.0	39.6	6.2
50- 60	23.1	32.5	5.7
60- 70	24.2	42.2	6.5
70- 80	25.5	33.6	5.8
80- 90	22.5	60.5	7.7

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APPENDIX C

ISOMETRIC CONTRACTIONS 30%

TIME (SECONDS)	MEAN X	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	5.1	18.1	4.25
10- 20	5.1	14.9	3.87
20- 30	5.6	9.3	3.0
30- 40	7.4	17.1	4.1
40- 50	7.6	17.6	4.1
50- 60	8.3	22.6	4.7
60- 70	8.0	11.4	3.3
70- 80	9.8	28.7	5.3
80- 90	11.1	36.9	6.08
90-100	7.5	5.6	2.3
100-110	9.3	5.3	2.3

ISOMETRIC CONTRACTIONS 40%

TIME (SECONDS)	MEAN X	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	7.1	16.9	4.12
10- 20	7.9	12.7	3.5
20- 30	8.2	17.0	4.1
30- 40	9.2	15.0	3.8
40- 50	10.7	23.1	4.8
50- 60	12.7	19.0	4.3
60- 70	14.1	17.7	4.2
70- 80	15.1	13.3	3.6
80- 90	17.4	47.3	6.8
90-100	19.5	4.5	2.1
100-110	21.5	24.5	4.9

ISOMETRIC CONTRACTIONS 50%

TIME (SECONDS)	MEAN X	VARIANCE (S^2)	STANDARD ERROR OF THE MEAN ($\frac{S}{\sqrt{N}}$)
0- 10	10.3	59.1	7.6
10- 20	11.0	45.7	6.7
20- 30	11.8	36.1	6.0
30- 40	13.0	39.2	6.26
40- 50	15.5	53.1	7.2
50- 60	18.7	52.5	7.2
60- 70	18.5	73.6	8.5
70- 80	21.5	84.5	9.1

APPENDIX D

ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
0 TO 10 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.24327466E+03	81.09	3	41.0	0.013300
ERROR	0.71170044E	19.77	36		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	10.2	9.4	7.7	3.8
1	3.8	* 6.4	* 5.6	3.9	
2	7.7	2.5	1.7		
3	9.4	.8			
4	10.2				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS 10 TO 20 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.53847437E+03	179.49	3	6.62	0.001121
ERROR	0.97630078E+03	27.12	36		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	14.7	10.7	8.8	4.5
1	* 4.5	*10.2	* 6.2	4.3	
2	8.8	5.9	1.9		
3	10.7	4.0			
4	14.7				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOTONIC TESTS

ANALYSIS OF VARIANCE AND NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS 30 TO 40 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.78087109E+03	260.29	3	8.27	0.000259
ERROR	0.11335039E+04	31.49	36		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	17.2	12.3	10.1	4.9
1	4.9	*12.3	* 7.4	* 5.2	
2	10.1	* 7.1	2.2		
3	12.3	4.9			
4	17.2				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
20 TO 30 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.68407422E+03	228.02	3	6.71	0.001028
ERROR	0.12227031E+04	33.96	36		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	16.7	11.7	10.2	5.1
1	5.1	*11.6	* 6.6	5.1	
2	10.2	* 6.5	1.5		
3	11.7	5.0			
4	16.7				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS 40 TO 50 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.66376953E+03	221.26	3	9.01	0.000169
ERROR	0.81050391E+03	24.56	33		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	19.0	14.3	10.6	7.0
1	7.0	*12.0	* 7.3	3.6	
2	10.6	* 8.4	3.7		
3	14.3	* 4.7			
4	19.0				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
50 TO 60 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.10915352E+04	363.84	3	13.74	0.000009
ERROR	0.82063672E+03	26.47	31		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	23.167	16.0	10.9	7.1
1	7.1	*16.067	* 8.9	3.8	
2	10.9	*12.267	5.1		
3	16.0	* 7.167			
4	23.167				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
60 TO 70 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.99062109E+03	330.21	3	7.55	0.000705
ERROR	0.12683516E+04	43.74	29		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	24.250	16.667	12.200	7.000
1	7.0	*17.250	* 9.667	5.200	
2	12.200	*12.050	4.467		
3	16.667	* 7.583			
4	24.250				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
70 TO 80 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.99505469E+03	331.68	3	7.55	0.000806
ERROR	0.11868164E+04	43.96	27		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	25.500	17.571	12.700	8.000
1	8.000	*17.500	* 9.571	* 4.700	
2	12.700	*12.800	4.871		
3	17.571	* 7.929			
4	25.500				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
80 TO 90 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.56228516E+03	187.43	3	3.79	0.024155
ERROR	0.11382344E+04	49.49	23		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS	22.500	18.333	13.667	8.400
1	8.400	*14.100	9.933	5.267	
2	13.667	8.833	4.667		
3	18.333	4.167			
4	22.500				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
100 TO 110 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.25402979E+03	127.01	2	3.61	0.047905
ERROR	0.63254175E+03	35.14	18		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		19.333	12.625	9.000
1	9.000		*10.333	3.625	
2	12.625		6.708		
3	19.333				
4					

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOTONIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
110 TO 120 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.37057666E+03	185.20	2	5.73	0.013297
ERROR	0.51752881E+03	32.35	16		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		24.000	13.286	9.300
1	9.300		*14.700	3.986	
2	13.286		*10.714		
3	24.000				
4					

*SIGNIFICANT AT THE 0.05 LEVEL

APPENDIX E

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
10 TO 20 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.17419971E+03	87.10	2	3.55	0.042661
ERROR	0.66180029E+03	24.51	27		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		11.000	7.900	5.100
1	5.100		* 5.900	2.800	
2	7.900		3.100		
3	11.000				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
20 TO 30 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.19386646E+03	96.93	2	4.64	0.018480
ERROR	0.56360034E+03	20.87	27		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		11.800	8.200	5.600
1	6.600		* 6.200	2.600	
2	8.200		3.600		
3	11.800				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS 30 TO 40 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.15331030E+03	76.66	2	3.30	0.052835
ERROR	0.60400024E+03	23.23	26		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		13.000	9.200	7.400
1	7.400		* 5.600	1.800	
2	9.200		3.800		
3	13.000				

*SIGNIFICANT AT THE 0.05 LEVEL

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ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
40 TO 50 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.27804419E+03	139.02	2	4.66	0.019498
ERROR	0.71595581E+03	29.83	24		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		15.500	10.778	7.600
1	7.600		* 7.900	3.178	
2	10.778		4.722		
3	15.500				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
50 TO 60 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.44672876E+03	223.36	2	7.52	0.003236
ERROR	0.65303125E+03	29.68	22		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		18.714	12.750	8.300
1	8.300		*10.414	4.450	
2	12.750		* 5.964		
3	18.714				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
60 TO 70 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.32244434E+03	161.22	2	6.20	0.010882
ERROR	0.38983350E+03	25.99	15		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		18.500	14.167	8.000
1	8.000		*10.500	6.167	
2	14.167		4.333		
3	18.500				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
70 TO 80 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.20878955E+03	104.39	2	3.92	0.055256
ERROR	0.26613354E+03	26.61	10		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS		21.500	15.167	9.800
1	9.800		*11.700	5.367	
2	15.167		6.333		
3	21.500				

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
90 TO 100 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.19200000E+03	192.00	1	35.72	0.003938
ERROR	0.21500000E+02	5.38	4		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS			19.500	7.500
1	7.500			*12.000	
2	19.500				
3					

*SIGNIFICANT AT THE 0.05 LEVEL

ISOMETRIC TESTS

ANALYSIS OF VARIANCE AND
NEWMAN-KEULS COMPARISON BETWEEN
ORDERED MEANS
100 TO 110 SECONDS

ANALYSIS OF VARIANCE

SOURCE	SS	MS	DF	F	P
GROUPS	0.17763330E+03	177.63	1	15.15	0.030066
ERROR	0.35166748E+02	11.72	3		

NEWMAN-KEULS COMPARISON BETWEEN ORDERED MEANS

		4	3	2	1
	MEANS			21.500	9.333
1	9.333			*12.167	
2	21.500				
3					

*SIGNIFICANT AT THE 0.05 LEVEL